Citation

Okada, Alexandra (2024). A self-reported instrument to measure and foster students’ science connection to life with the CARE - KNOW - DO model and open schooling for sustainability. Journal of Research in Science Teaching (Early access).

URL

https://oro.open.ac.uk/98005/

License

(CC-BY 4.0) Creative Commons: Attribution 4.0

https://creativecommons.org/licenses/by/4.0/

Policy

This document has been downloaded from Open Research Online, The Open University's repository of research publications. This version is being made available in accordance with Open Research Online policies available from Open Research Online (ORO) Policies

Versions

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding
A self-reported instrument to measure and foster students' science connection to life with the CARE-KNOW-DO model and open schooling for sustainability

Alexandra Okada

Rumpus Research Group, School of Education, Childhood, Youth and Sport, Faculty of Wellbeing, Education & Language Studies, The Open University, Milton Keynes, UK

Abstract

National governments are concerned about the disconnection of young people from science, which hampers the development of a scientifically literate society promoting sustainable development, wellbeing, equity, and a green economy. Introduced in 2015 alongside Agenda 2030, the “open schooling” approach aims at enhancing students' science connections through real-life problem solving with families and scientists, necessitating solid evidence for scalability and sustainability. This study conceptualizes “science connection,” a term yet under-explored, as the integration of science’s meaning and purpose into personal, social, and global actions informed by socioscientific thinking. It details a novel 32-item self-report questionnaire developed and validated from insights of 85 teachers into “science connection”-enhanced learning. A new consensual qualitative analysis method with visual and textual snapshots enabled developing quantitative measures from the qualitative findings with rigor. The multilanguage instrument provided just-in-time actionable data,
enhancing the immediacy and applicability of the feedback to 2082 underserved students aged 11–18 across five countries participating in open schooling activities using the CARE-KNOW-DO model. This innovative feature supports open science and responsible open research, offering real-time insights and fostering immediate educational impact. Exploratory and confirmatory factor analyses revealed five components of science connection: Confidence and aspiration in science; Fun participatory science with teachers, family, and experts; Active learning approaches; Involvement in-and-outside school science activities; and Valuing science’s role to life-and-society. Many students felt connected to science—Brazil: 80%, Spain: 79%, Romania: 73%, Greece: 70%, UK: 57%—with boys: 75%, girls: 73%, nonbinary students: 56%. These differences need in-depth research. Results suggest that science connections decline from the primary to secondary education, but the CARE-KNOW-DO model may reengage older students. A robust science connection enhances scientific literacy and builds science capital. This instrument aids policymakers, educators, and learners in identifying factors that facilitate or impede students’ engagement with science for sustainable development efforts.

**KEYWORDS**

CARE-KNOW-DO model, fun participatory science, open schooling, science capital, science connection, socioscientific thinking, sustainability

### 1 | INTRODUCTION

In this study, I argue for the pressing necessity of developing and validating an instrument capable of fostering and measuring students’ science connection to life. This approach is essential for fostering purpose-driven relationships using science for personal well-being, improved community life, and global sustainability. This endeavor aims to enrich authentic learning approaches guided by principles that enhance students’ socioscientific thinking within open schooling settings. To prepare students for the future, education must link the knowledge they learn with real life and real-world challenges (Fortus et al., 2022) through humanistic school science (Aikenhead, 2023). This approach, where students work on real problems alongside other people, such as professionals and citizens, is known as open schooling (Mulero et al., 2022; Okada & Sherborne, 2018; Wam et al., 2022).
The “open schooling” concept, established by the European Union in 2015, emerged in parallel with the United Nations’ Agenda 2030 and the Paris Agreement. It seeks to accomplish education that fosters sustainable development and responsible citizenship with real-world problem solving involving students, families, scientists, and teachers.

“Open schooling means where schools, in cooperation with other stakeholders, become an agent of community well-being; families are encouraged to become real partners in school life and activities; and professionals from enterprise, civil and wider society are actively involved in bringing real-life projects into the classroom” (from Hazelkorn et al., 2015, p. 10; EC, 2022).

Contemporary education with science-in-context (Bencze, 2017; Bencze et al., 2020) connected to real-life issues is necessary for empowering youth with socioscientific thinking for a sustainable future, at personal, societal, and professional levels (Xue & Larson, 2015). There is a growing gap in qualified individuals for the increasing green job market, and 20.6% of students lack basic proficiency (EC, 2016; McCloy et al., 2020) and 43.2% in Brazil (OECD, 2023). Open schooling aims to address this issue by integrating formal and informal education, encouraging real-world problem solving and community involvement (Hazelkorn et al., 2015). It fosters scientific interest and career awareness among students, both in school and in real-life settings beyond the classroom, preparing them for future experiences (Okada et al., 2024).

However, there is an imperative need to develop an instrument that provides evidence regarding the benefits of novel approaches such as open schooling and to identify recommendations for overcoming barriers to achieving inclusivity and sustainability. First, schoolteachers already experience lack of time due to high workloads in delivering curriculum content with a focus on standardized tests (Klaver et al., 2023), making it difficult for them to incorporate anything that lacks evidence supporting students’ attainment (Anwar et al., 2022). Second, scientists, families, and community members—seen as key sources of knowledge (Klaver et al., 2023)—are often too busy to attend activities and need to perceive the value of their involvement and contribution to students’ academic achievements.

This study introduces the development, implementation, and validation of the CONNECT-science instrument within the open schooling approach with open educational resources underpinned by the CARE-KNOW-DO model (Okada, 2024; Okada & Gray, 2023; Okada & Sherborne, 2018). The instrument aimed to gain valuable insights into the factors and challenges that influence the cultivation of students’ meaningful and purposeful science connection to life.

The empirical research exploring students’ science connection is sparse, with scant instruments measuring learners’ capacity to apply scientific knowledge in personal contexts.

For example, a Nigerian study evaluated students’ ability to connect school-taught chemistry to home experiences using a six-question survey focused on evaporation (Oloruntegbe & Ikpe, 2011). A Korean study assessed preservice teachers’ ability to connect the nature of science to societal needs with eight open-ended questions (Seung et al., 2009). Moreover, a study examined nonscience majors’ connection of science to their career goals via the 30-question Science Motivation Questionnaire (Glynn et al., 2009). These studies, however, were limited by small sample sizes, narrow scientific focus, and lack of a comprehensive understanding of what “connecting” with science means for students. Two research projects provided useful insights into students’ attitudes in science considered in this study but did not delve into their direct connection with science. The ROSE questionnaire, with 268 questions across 7 categories, evaluates
students’ interest in science (Schreiner & Sjøberg, 2004; Sjøberg & Schreiner, 2010; Yang et al., 2017), while the ASPIRE questionnaire’s 13 items examine students’ science-related cultural and social capital, also known as science capital (Archer et al., 2015; Moote et al., 2020, 2021). Based on Pierre Bourdieu’s concept of “cultural capital,” science capital refers to the set of knowledge, attitudes, experiences and resources related to science that a person possesses (Archer et al., 2012, 2015). The limitations include the large length of the ROSE questionnaire and the shortness of the ASPIRE questionnaire, which was created for the UK context. Furthermore, both were developed more than a decade ago based on theoretical dimensions without considering the perspectives of science teachers, which is crucial for informing educational enhancements. The development of a new instrument aims to overcome previous limitations by incorporating teacher insights into science education and student feedback on learning experiences across diverse contexts, including four European countries and Brazil; factoring in gender, age, and location.

2 PRINCIPLES AND CONSTRUCTS

2.1 The “science connection” concept

The term “science connection” is commonly used in science education in the context of student-centered interdisciplinary approaches climate literacy (Quarderer et al., 2021); real-life or world phenomena (Bayram-Jacobs et al., 2019; Löfgren et al., 2023); emotion (Fu & Clarke, 2023); argumentation (Khishfe, 2023); key capitals (Tan et al., 2024); among others. However, this concept remains poorly conceptualized and underexplored in the literature. To date, no research has been found that differentiates the nuances of science connection in, with, and to/for life. This study considers these distinctions key for investigating the evolving process of students connecting science in, with, to, and for their lives.

This multidimensional concept encompasses students connecting science “in their life” as part of their living experiences (Aikenhead, 2006, 2023), “with life” through partnerships with others (Cian et al., 2022; Cohen, 2012), and “to/or for life” with an embedded purpose toward sustainability (Weinstein et al., 2023). Unlike “engagement,” which involves active participation in learning scientific concepts and processes, “connection” suggests a deeper, more personal, global, and future bond with science, drawing inspiration from Hodson (2011) and expanded from ideas by Penuel et al. (2024). This bond fosters understanding, emotional relevance, and a sense of belonging extending beyond mere participation to include personal identification with science and its implications for well-being, community improvement, and sustainability (Aikens et al., 2016; Okada & Gray, 2023).

The concept of “connection” in science education, as derived from Kozoll and Osborne (2004, 2006) is about fostering students’ identification with science so that it becomes a significant part of their lives. This connection is explored through a hermeneutic and phenomenological framework that considers the enrichment of the student’s “lifeworld”—the subconscious tapestry of lived experiences, values, and emotions that inform decision-making and actions influenced by science (Gonsalves et al., 2021; Habermas, 1987; Heidegger, 1962; Niemi, 2017).

Osborne et al. (2003) and Schiepe-Tiska et al. (2016) align with this perspective, identifying affective attitudes toward science—including emotions, beliefs, and values about the field and its societal relevance—as essential to recognizing science’s relevance and interest (Kind &
Affective attitudes (Radoff et al., 2019) are influenced by the personal importance of science, self-concept in science, motivation, enjoyment, influences from peers and family, classroom dynamics, and science achievement.

Expanding upon this, Ratcliffe and Grace (2003, p.29) highlight “the connection between scientific literacy and citizenship.” They advocate for science education to intentionally connect with everyday life, emphasizing socioscientific issues (SSIs) as crucial for applying scientific knowledge to societal needs. Incorporating SSI into curricula enables students to acquire scientific literacy, skills, and ethical awareness necessary for tackling real-world problems, fostering responsible actions (Amos & Levinson, 2019; Zeidler et al., 2019).

Furthermore, Fortus et al. (2022) argues for a broader understanding of science education that encompasses the affective domain, suggesting that emotions and embodied experiences influence learning and engagement. Similarly, Herman et al. (2020) note the importance of developing emotive reasoning with perspective-taking, righteous indignation, within students, equipping them to address challenges appropriately. The role of emotion in science, as discussed by Avraamidou (2020) and Davidson et al. (2020), is highlighted as critical for the development of authentic scientific identities, emphasizing the interplay between consciousness and emotions in shaping one’s scientific persona. Epistemic affect and epistemic emotions are shown to have utility in scientific practice. Such feelings can guide subsequent steps in scientific inquiries and foster a stance of perseverance, tenacity, and a compelling need-to-know. Finally, a radical stance is presented by Hodson (2020), who calls for a politicized, action-oriented approach to SSI in education. His model prioritizes recognizing science’s societal implications and its association with power dynamics, aiming to cultivate awareness and encourage students to take informed sociopolitical action. This pedagogical model resonates with Freire's (2021) “problematizing education,” which seeks to transform learners into active, critical thinkers through a process of dialogue and reflection toward praxis—transformation with justice-oriented pedagogical practice supporting inclusion, diversity and equity in science education (Calabrese Barton et al., 2021).

In this study, to explore “science connection,” I combine foundational concepts of cognitive, affective, and social attitudes toward science, as highlighted by Osborne et al. (2003); Osborne (2017); Calabrese Barton et al. (2021) and Fortus et al. (2022), with theories about the meaning and identity found in science (Avraamidou, 2020; Davidson et al., 2020; Kozoll & Osborne, 2004). I also incorporate pedagogies that promote action, empowerment, and freedom (Freire, 2021; Hodson, 2020; Ratcliffe & Grace, 2003). From this synthesis, I define “science connection” to life as integrating the meaning and purpose of science into personal, social, and global contexts to encourage sustainable futures. This science connection, in my conceptualization, highlights how individuals engage with science's relevance to their lives, stimulating interest in scientific topics, and fostering active participation in scientific endeavors at individual, national, and global levels over time. This involvement not only spans current generations but also extends to ensuring a sustainable future for those to come. It means connecting science to sustainability through education that is inclusive, engaging, and forward-looking, taking into account current realities as well as the well-being of the planet. This connection is essential for educating students to become responsible, self-directed, and reflective thinkers who are adept at analyzing real-world issues (“reading”) and creating sustainable solutions (“writing”) (Freire, 2021). In my research, students' science connection to life signifies the continuous application of socioscientific thought to decision-making and (Gijbels et al., 2005) problem solving to shape sustainable future. This process involves critically and actively reflecting on
scientific advancements in concert with human needs, societal demands, and planetary health, and taking intentional actions to meet personal, local and global challenges.

2.2 | The CARE-KNOW-DO model

The CARE-KNOW-DO model is a forward-thinking approach to learning that emphasizes three key components: caring about real-world issues, acquiring knowledge of science concepts and skills in context, and actively engaging in problem solving and decision-making both within and outside the school environment, collaborating with communities and professionals (Okada & Gray, 2023; Okada & Sherborne, 2018). This model, which underpinned three large projects in Europe and Brazil, is designed to enhance students' educational experiences by fostering a deep connection between their learning and real-life applications, focusing particularly on developing competences and skills relevant for the future (Bianchi, 2020; Malagrida et al., 2024; Okada et al., 2024). By integrating care for relevant issues, scientific knowledge, and practical problem-solving skills, the CARE-KNOW-DO model aims to empower students to become proactive agents of positive change in their communities and global networks.

This study examines teachers’ and students’ perceptions of fostering meaningful connections with science. It provides insights into interventions, outcomes, benefits, and challenges, drawing on experiences from school communities engaging with the CARE-KNOW-DO model. I employ triangulation, combining teachers’ accounts of pedagogical practices including assessments with students’ reflections on their learning experiences to inform a self-report questionnaire designed to measure and foster connections to science. I assert that affective engagement in science is crucial for students’ intrinsic comprehension and motivation. I advocate that inquiry-oriented learning that includes affective involvement is essential for enhancing students’ scientific literacy and fostering a positive disposition toward science.

2.3 | Constructs and research questions

Drawing on Osborne et al.’s (2003) review and the seminal work by Klopfer (1971), I have identified six attitudes that exemplify students’ science connections to life. These form the basis of the CONNECT-science instrument, which comprises three subscales:

1. **CARE**: Reflecting students’ emotional responses to science, capturing their enjoyment and interest in science-related activities and potential careers.
2. **KNOW**: Highlighting intellectual engagement, indicating how students develop interests and knowledge through inquiry-based thinking.
3. **DO**: Concentrating on the attitudinal and behavioral aspects, showing favorable attitudes toward science and the embodiment of scientific attitudes in everyday life.

Through this lens, my research offers a comprehensive view of how educational initiatives can nurture a profound link between science and life, preparing students to address present and future societal challenges. Table 1 presents the key constructs for designing the CONNECT-science instrument, integrating CARE-KNOW-DO (Okada & Sherborne, 2018; Okada & Gray, 2023) with Affective – Cognitive – Social behaviours in science (Osborne et al., 2003).
This study aims to investigate the nuances of students’ connections to science, as understood by both teachers and students. The research questions are twofold: First, how do teachers perceive students’ science connections in terms of affective engagement (enjoyment and interest), cognitive understanding (knowledge and inquiry skills), and behavioral actions (attitudes and interactions)? Second, what reflections do students have about their science connections, especially in the context of effective learning as perceived by their teachers? This research combines teacher evaluations of student learning and student self-reflection, thereby informing the construction and validation of the CONNECT-science instrument.

### METHODOLOGICAL APPROACH

In this open research study with open data, I employed a mixed methods approach, combining teachers’ qualitative data to develop quantitative measurements for examining students’ science connection. This enabled the exploration of learners’ own views related to their open schooling experience with the CARE-KNOW-DO resources and facilitated a more comprehensive understanding of the research problem by triangulating findings from different perspectives.

Utilizing the CARE-KNOW-DO model, a network of around 3500 science educators from EU-funded open schooling projects (weSPOT, ENGAGE, CONNECT) across Europe and South America (Brazil) has engaged students in science topics that resonate with their daily lives. These open educational resources promote inquiry, knowledge acquisition, and proactive involvement, enhanced by collaboration with families and professionals in and out of the classroom. The educators were invited to participate in an EU-funded conference and contribute to this study with open data.

### 3.1 Participants teachers

Eighty-five participants from this network of open schooling projects from the United Kingdom including Romania, Greece, Brazil, and Spain contributed to this mixed-methods study. These included 15 science educator-presenters and 70 science educator-attendees, representing classes of 30–35 students on average, who attended the EU-funded international event. The data generated were captured from the presentations and discussions centered on practices, learning outcomes, and the challenges and drivers of using the open schooling approach and CARE-KNOW-DO resources. Some coordinators implemented these resources across entire school.
3.2 CARE-KNOW-DO resources: Design elements and examples

The design elements of open schooling embody the CARE-KNOW-DO principles, such as: (1) Real-life SSIs that engage young people, aligned with the 17 Sustainable Development Goals, to foster care and concern. (2) Learning materials that are integrated into the curriculum, enabling students to build and apply knowledge in problem-solving and decision-making activities. (3) Guidelines that encourage teachers to engage students with fun participatory science, along with, science professionals, and family communities, to promote community engagement, awareness, and knowledge exchange. These resources were published in English, Spanish, Greek, Romanian, and Portuguese and presented across four platforms UPd8, weSPOT, ENGAGE, and CONNECT by different set of partners.

Figure 1 showcases resources featuring SSI that activate imagination, such as eating insects; spark intriguing curiosity, like poo transplants; encourage critical views, for example, banning Coke; promote justice, through the issue of microplastics; inspire environmental activism, as in rewilding; raise concerns, notably about a $2^{\text{o}}$ temperature rise; and foster entrepreneurship, with eco-friendly phones, among others. These dilemmas enable teachers to guide students in decision-making with open science and foster responsible research and innovation (RRI) skills with participatory science based on the CARE-KNOW-DO model.

The resources categorized by the three SDG layers—the biosphere, society, and economy—were underpinned by the CARE-KNOW-DO model enhanced by teachers, families, community members and professionals. Partnerships in open schooling play a vital role in authentic education (Sherborne, 2017), fostering collaboration between schools, universities, and societies to address real-world problems through formal, nonformal, and informal learning.

FIGURE 1 Socioscientific thinking about sustainability issues with fun participatory science with Mastery Science. CCBY Okada et al. (2024).
Figure 2 illustrates two lesson plans from British schools, focusing on one of the examples: the “Rewilding”—biosphere (SDG 15 Life on Land). The first plan presents a traditional lesson focused on knowledge and skills, while the second is based on open schooling with the CARE-KNOW-DO model, highlighting a shift from conventional knowledge-based teaching to a more dynamic, science-to-life approach with fun participatory science in the United Kingdom. Teachers activate students’ curiosity with a real-life issue using WWF article and videoclip related to unbalanced ecosystems affecting biodiversity. Students acquire and apply knowledge about food webs to discuss which animal to rewild with their families. To prepare a campaign at their school-community with a persuasive poster they analyze their arguments with a professional expert.

Figure 3 illustrates the adaptation of the “Rewilding” resource to the Brazilian context. The CARE-KNOW-DO approach focuses on engaging students with tangible issues, for example, biodiversity loss, encouraging the application of ecosystem knowledge to real-world challenges through projects that develop life skills and raise community awareness.

The elementary school students proposed the use of traffic signs to protect animals from accidents caused by drivers, aiming to preserve the biodiversity of the world’s largest urban forest located in São Paulo. They wrote a letter with knowledge that they learned and convinced the council to install the signs to protect mammals like capibaras (Figure 3). A key advantage of integrating the CARE-KNOW-DO lesson plan into the curriculum is its combination of empathy, contextual understanding, and hands-on action. Students had the opportunity to interact with professionals in various settings, including national parks, zoos, and science centers, developing projects including numeracy, literacy, science, arts and technologies.

Another example focuses on students connected with real-life energy challenges in partnership with their families and professionals. Figure 4 shows various educational projects that incorporated the CARE-KNOW-DO model into learning about SDG 7, affordable and clean
energy. Project partners from universities and the local community with practical expertise were readily available to contribute their knowledge. Researchers gave interviews and were accessible for frequently asked questions. Some teachers were able to take their students to universities or companies, while others arranged for professionals to visit schools, either in person or online. The Science UpD8 project adopted a holistic educational approach to wind energy, engaging students in the implications (care), scientific principles (knowledge), and communication of information (action) about wind energy, including turbine operation and environmental effects. They were interested in what wind is and why it can be both dangerous and useful. They learned about the mechanics and impacts of wind power. With their families, they discussed the environmental effects, expressing both curiosity and concern about 100 mph winds that could kill people. They produced an infographic to disseminate in their community. In the ENGAGE project, students approached practical energy conservation within European households. They became invested in the consequences of electricity consumption, learned about reduction strategies with families and professionals, and created a blog post to educate their community. The weSPOT initiative focused on the question, “What is microclimate design and how can we promote energy efficiency?” The project leveraged mobile technology to allow students to explore green energy solutions such as electric cars and solar panels. Their care for the environment motivated them to acquire knowledge and make practical recommendations, culminating in presentations at an international conference. In CONNECT, an engineer and a teacher supported students in researching energy-saving devices using AI mapping tools. They engaged in discussions with parents to enhance their comprehension and communication skills related to energy efficiency. Students analyzed various examples such as solar cap chargers, energy-efficient light bulbs, programmable thermostats, insulated tea cups with lids, and high-efficiency appliances. They also produced a fundraising campaign (Okada, 2024). Throughout these projects, students exhibited a
learning journey from initial concern to informed action, embodying the emotional, intellectual, social and active elements of the CARE-KNOW-DO.

3.3 | Participants students

A total of 2082 students from schools across the United Kingdom, Spain, Romania, Greece, and Brazil participated in this study. Their teachers, involved in our EU-funded projects (weSPOT, ENGAGE, CONNECT), engaged them with science activities using open schooling resources based on CARE-KNOW-DO. These students completed the self-reported CONNECT-science questionnaire in their local languages and provided demographic data. The student participants were predominantly European (59%) and South American (41%), spanning ages 11–17 across all seven grades: 15% from primary, 27% from lower secondary, 35% from middle, and 23% from upper secondary schools. The gender distribution was 43% male, 56% female, and 1% other. Most of the participants came from underserved backgrounds, with a majority attending public state schools that offer free meals. Notably, 84% did not have parents working in science-related fields, 60% lacked personal computers or tablets, and 12% had no access to the internet or mobile devices.
3.4 | Mixed methods research

This study utilized an integrated mixed-methods approach, combining thematic snapshots and visual artifacts to create the CONNECT-science instrument, as detailed in Appendix 1. “Snapshots,” as defined by Weisbuch et al. (2017), are records of participant-generated samples from events such as public conferences. In this study, “thematic snapshots” refer to collections of significant moments that encapsulate participants’ perspectives and experiences around a central theme.

The robustness of this approach is demonstrated through its public presentation and spontaneous discussion among science educators during knowledge exchange sessions. These sessions involved natural conversations where educators freely shared learning successes, challenges, experiences, and contexts, rather than structured interviews.

The data were gathered from presentations and discussions involving science educators. Presenters and audience members exchanged insights into the advantages and hurdles of teaching real-world problems, including curriculum delivery and exam preparation challenges. Teachers also shared their observations on student learning and science engagement, discussing instances of student disconnection from various topics and activities. Notably, some teachers have positioned themselves as parents, using open schooling materials at home with their children, underscoring the value of these resources.

An impartial observer—illustrator—captured and shared visual snapshots in real time (see Figure 5), representing data under the respective domains independently. This facilitated a consensual qualitative research approach (Hill, 2012).

The illustrator, a neutral party from the artistic field and not from science education, highlighted the main discussion categories in real time. Our qualitative data consisted of two types of snapshots: textual, from teachers’ narratives, and visual, from illustrative discussions, allowing for the creation of consensual perceptions about cultural influences on shared cognitions. This innovative approach to participatory consensual research facilitated participant reflection, interpretation, and interaction, offering a comprehensive and integrated view of each practice discussed and the event as a whole. This enhanced knowledge exchange and capacity building, positively impacting the professional development of the participants.
3.5 | Instrument development

The initial step involved constructing a qualitative database from teacher narratives, which was stored in an open online data repository. Data analysis was performed using Nvivo26, guided by deductive categories related to scientific capital and affective engagement, and subcategories derived from inductive analysis of snapshots. Two expert partners, a science education curriculum designer and a science teacher educator, assisted in validating the emerging categories and inductive items from the teacher discussions.

The “thematic snapshots” facilitated the identification of sociocultural practices within open schooling and formal/informal learning. Augmented Sociocultural Discourse Analysis (Johnson & Mercer, 2019) was employed to explore situated practices and examine professional discourse, combining thematic content analysis, conversation analysis, and corpus linguistics.

The subsequent section will describe the instrument development process informed by themes related to CONNECT-science, grounded in six constructs identified from the literature and teacher perspectives on student learning and engagement with science.

4 | INSTRUMENT DEVELOPMENT AND VALIDATION FRAMEWORK (SNAPSHOTS)

The thematic analysis of textual and visual snapshots utilized a codebook created by the author for rigor (Roberts et al., 2019). This codebook integrated both inductive data-driven and deductive theory-driven techniques, drawing from Fereday and Muir-Cochrane (2006) and Braun and Clarke (2006). It underwent evaluation by a science curriculum developer and two educators who supported the European Projects to ensure clarity, consistency, and replicability.

The qualitative data yielded identifiable units of meaning, recognized as subthemes, which facilitated the identification of subconstructs. These subconstructs informed the development of the CONNECT-science questionnaire. The analysis, supported by the codebook, confirmed 35 reflective statements regarding student learning, categorized according to the six constructs related to CARE-KNOW-DO (Appendix 1), guiding the creation of questionnaire items.

4.1 | Teachers’ views about what students’ DO in-and-outside school

Teachers highlighted how students were engaged by doing science activities in their home lives. This points to the importance of affective engagement. The open schooling approach encouraged them to recognize science around them, valuing what they found, extending, and maintaining interest in the topic beyond school. This in turn helped teachers realize that students were doing activities (science actions) outside the lesson that were helping them learn independently and collaboratively with others, discussing their knowledge of science in real contexts and understanding that science is a subject that exists inside and outside school.

From the textual snapshots Table 2, five items emerged related to “what students DO in science?,” (1) “students were doing science activities outside school,” (2) “searching for extra
TABLE 2  Textual snapshots 1—What students DO outside school.

<table>
<thead>
<tr>
<th>Item</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Everything they did in science was infused into the environment outside.</td>
</tr>
<tr>
<td>(2)</td>
<td>If students have a question, then they go out, search, and find (out) that information to answer that question themselves. It’s been a lot of learning things independently.</td>
</tr>
<tr>
<td>(3)</td>
<td>They are getting involved in this. They are doing things for themselves. It encourages them to seek and read about science themselves based on their interests, needs and application.</td>
</tr>
<tr>
<td>(4)</td>
<td>It’s allowing them to kind of look at and talk about the world around them.</td>
</tr>
<tr>
<td>(5)</td>
<td>Students are asking interesting questions to learn science, thinking independently about stuff. What we can see is that students are now starting to ask the what-if questions ... They didn’t get any of this before.</td>
</tr>
</tbody>
</table>

FIGURE 6  Visual snapshots “Care” contextualized engagement, “Know” building concrete foundation, Learners “Do” the work.

information related to science activities,” (3) “reading about science at home,” (4) “talking about the world around them using science,” and (5) “creating questions.” (see Appendix 1).

From the reflective discussion between speakers and attendees, three strong aspects of pedagogical practices were identified that were illustrated by visual snapshots (Figure 6).

These snapshots captured what was significant from teachers’ views for (i) enhancing students’ deep learning, such as (ii) providing a context-based curriculum based on real-life issues that students care about, (iii) building knowledge rather than pouring it into students’ heads and letting the students do the work. In line with the textual snapshots, these findings suggest that students’ active agency (Reeve & Tseng, 2011) is key for independent learning and self-efficacy skills.

Elucidating the characteristics of science classroom activities that influence “task value” could contribute significantly to enhancing the overall quality of students’ experiences (Osborne et al., 2003). “Task value” means the extent to which an individual perceives that a specific task can meet their personal needs or goals. It encompasses three key components: (a) interest, reflecting the enjoyment derived by students when engaging in a task; (b) importance, signifying the degree to which students consider it crucial to perform well in a task; and (c) utility, indicating the extent to which an individual believes a task is valuable in achieving future objectives (Eccles & Wigfield, 1995). This study suggests that “task value” outside the classroom,
as noted by teachers who use CARE-KNOW-DO resources for open schooling, can further enhance curriculum activities by fostering students’ science connection based on their interests, needs, and practical experiences.

4.2 Teachers’ views about what students KNOW about science

Teachers discussed their views in terms of the knowledge that students were building with opportunities to discuss them with experts and to talk and think with peers and family members, which they needed to consolidate their science knowledge. Teachers highlighted that CARE-KNOW-DO provided hooks for helping students engage and build a science foundation (scheme of work) linked to new knowledge, which enabled them to create questions and share ideas. Teachers also acknowledged challenges, including students’ difficulties using math in science. They also highlighted the importance of open schooling as an authentic inquiry approach for students to develop knowledge in a real context, which helps students become more confident “truly getting science and understanding concepts.”

From the textual snapshots Table 3 about what students KNOW or (*) need to know about science, five items emerged: (6) doing “science projects with other people,” (7) using science talking about issues, (8) using science to “come up with questions and ideas,” (9) using “maths to solve problems in science,” (10) building “knowledge in science,” and (11) justify views using arguments and evidence.

From the reflective discussion, three strong aspects of pedagogical practices were identified and illustrated via visual snapshots (Figure 7).

These visual snapshots (Figure 7) captured what was valuable from teachers’ views to help students build knowledge with: (i) feedback to improve learning, (ii) context folder linking everyday life scenarios with high standards to build science foundations, and (iii) guidance for students to use science skills in the real world. This finding shows how teachers can encourage self-efficacy by helping students connect knowledge to their own lives through specific actions, for example, talking about science.

**TABLE 3**

Textual snapshots 2—What students KNOW about science.

<table>
<thead>
<tr>
<th>Item</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>(6)</td>
<td>When students have the <strong>foundations</strong> in place, they are able to <strong>discuss what they know with experts</strong> and do <strong>inquiry projects</strong> with peers and enjoy <strong>science</strong> in a context that is relevant to them.</td>
</tr>
<tr>
<td>(7)</td>
<td>Students need to <strong>talk about science</strong>, they need to <strong>think about how science</strong> can be related to their everyday situations.</td>
</tr>
<tr>
<td>(8)</td>
<td>What students want “and have” are <strong>hooks</strong> that get them engaged. They can then build their scheme of work around these hooks and bring new knowledge, <strong>questions, and ideas</strong> in around that.</td>
</tr>
<tr>
<td>(9)</td>
<td>(*) There are some students who can do their maths in <strong>maths</strong> class, but as soon as they come into <strong>science</strong>, they can’t do it. Therefore, one of my questions is: why is that transferability not truly happening?</td>
</tr>
<tr>
<td>(10)</td>
<td>There was a vast difference between those children that <strong>truly got science</strong> and understood the <strong>concept of it using authentic inquiry</strong> activities and those children that truly didn’t have a clue.</td>
</tr>
</tbody>
</table>
Osborne et al. (2003) conducted studies that identified a moderate correlation between students’ science attitudes and their academic performance. These findings align with those reported by Jovanic and King (1998), Osborne and Collins (2000), and Simpson and Oliver (1990). When students find enjoyment and success in junior science courses, they tend to foster a lasting commitment to science. Importantly, the authors noted that students can excel in science without necessarily having a positive attitude. Inferring from this, it can be concluded that their commitment to science may not be as strong or enduring, highlighting the need for educators to promote academic excellence and positive engagement to foster a strong science connection.

In the context of this open schooling study, teachers confirmed that students who displayed confidence were more likely to enjoy science. Some students were confident in science but not in math. Teacher feedback and encouragement played a pivotal role in supporting students with lower confidence and those who were not high achievers. Conversely, students who disliked science and lacked confidence found it particularly challenging to connect with the subject. Opportunities for students to develop self-efficacy were relevant ways to express their science connection. Teachers noted that discussing real-life problems and solutions using science helped students become more confident as independent thinkers.

4.3 Teachers’ views about how students think about science in their lives and future

Teachers described that CARE-KNOW-DO activities were effective at influencing students’ perceptions of the relevance and value of science in their lives and society. They emphasized the importance of discussing the role of science in problem solving to make students aware of the skills required in various professional areas, such as socioscientific thinking, collaboration, and creativity. The resources provided an opportunity for students to think about the value of science. Teachers found that helping students understand the usefulness and importance of science in their lives led to increased enthusiasm and deeper thinking about science. Students were encouraged to consider knowledge schemes to aid in their decision-making. Students thought that learning science is useful in their daily life through CARE-KNOW-DO resources. They were increasingly more connected to science than students who completed low secondary school and did not have the opportunity to experience open schooling.
TABLE 4  Textual snapshots 3—How students think about science in their lives and future.

<table>
<thead>
<tr>
<th>Item</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12)</td>
<td>Discussing how science has been used to <strong>improve the quality-of-life</strong> has allowed students to think about its relevance and meaning (happy, healthy lives).</td>
</tr>
<tr>
<td>(13)</td>
<td>Youth will need science, technology, and maths knowledge to develop <strong>higher order thinking skills</strong> to <strong>identify issues, make choices and decisions</strong> in various areas that affect their lives.</td>
</tr>
<tr>
<td>(14)</td>
<td>Professionals in science use their <strong>curiosity and imagination</strong> for research and innovation.</td>
</tr>
<tr>
<td>(15)</td>
<td>It was useful for <strong>students to learn how to learn science collaboratively</strong> in and outside school. Students as future <strong>scientists should not work alone</strong>.</td>
</tr>
<tr>
<td>(16)</td>
<td>Starting from where the students are and helping them to use and expand their <strong>schemes to develop thinking skills</strong>.</td>
</tr>
<tr>
<td>(17)</td>
<td><strong>If the enthusiasm</strong> that we’ve got with the current year 7s who participated in the new <strong>activities carried through</strong>, the <strong>sky’s the limit</strong> truly for what these kids can achieve. A lot of kids were not able to see the <strong>relevance and usefulness</strong> of science because they did not have the opportunity.</td>
</tr>
</tbody>
</table>

Figure 8  Visual snapshots: design, discovery, and decisions supported by an active role in collaborative learning.

From the textual snapshots Table 4: How students think about sciences, six items emerged related to: (12) Science helps people around the world lead happy, healthy lives; and (13) Science, technology, and math are important for solving problems. (14) Scientists need to use their “imagination” while doing research. (15) Scientists “do not” work alone. (16) Science helps people learn to use “evidence when they make decisions.” (17) Learning Science will be useful in my daily life.

Three images (Figure 8) illustrate teaching practices for identifying contexts that enhance students’ socioscientific thinking and appreciation of the meaning and purpose of science in and for society. These practices include (i) critical thinking – asking why, (ii) creating new designs inspired by STEM professionals, making discoveries with scientists, and supporting decision-making with citizens. So that, (iii) groups of students will be constantly challenging and practicing collaborative learning where all students have a role to play in a science with enthusiasm and fun, such as scientists’ apprentices and partners.

In the literature on attitudes toward science, there is some disagreement about the link between attitude and achievement, with uncertainty about the dependent variable. Osborne et al. (2003) noted that the essential premise permeating much of the related research is that
attitude precedes behavior. Attitude is a mental and emotional readiness to respond to something in a certain way; it is formed through a combination of cognitive, emotional, and behavioral components, including beliefs, feelings, values, and dispositions about science. Behavior, on the other hand, is the observable action, reaction, or conduct of students—what they actually do in response to a situation or stimulus through verbal and nonverbal actions—influenced by their attitudes, beliefs, motivations, and learning (Woodard et al., 2024).

The findings of this study present two premises. First, attitudes can influence behavior; for example, older students with a negative attitude toward science over the years are less likely to engage with it. Second, behavior can shape attitudes over time, as observed in younger students who started studying science without a preformed attitude. The accumulation of positive experiences led to a more positive attitude. If their enthusiasm continues through secondary education, the result will be a strong science connection.

4.4 Teachers’ views about who students know and discuss science with

Teachers found that the CARE-KNOW-DO resources for students to interact with scientists and families, as well as with them, provided rich learning experience for students to enhance their understanding. Contact with science experts was also useful for them to learn more about professional careers that use science. Teachers and their interactions with family and community members helped students practice independent thinking and decision-making while considering diverse viewpoints. Parents value science as it fosters critical and creative thinking in children, which is crucial for their future. Encouraging and valuing children’s interest in science can be a motivating factor for them. Teachers providing opportunities for students to ask questions and explore topics they care about significantly contributed to their interest in science. Teachers who encouraged students’ exploratory and problem-solving learning approaches found the approach to be effective at fostering independent thinking and skill development.

From the textual snapshots Table 5—whom students know and discuss science with, six items emerged: (18) Students met some “people working with science to talk about what their jobs are like”; and (19) Science “knowledge and skills can help them to get a job.” (20) Their family thinks science is interesting and (21) important for their future; (22) Teacher has explained the “importance of science in life and society,” and (23) learn science to think.

From the reflective discussion, three strong aspects of pedagogical practices were identified and illustrated by visual snapshots (Figure 9), which captured what was most valuable from teachers’ views related to students’ interactions with other actors: (i) Students can develop their identity by feeling that they are in this process of real-world problem solving and can reflect together. (ii) Help students bridge the gap debating big ideas relating them to real world with real societal actors use science as the frame. (iii) Students’ interactions give them a rich experience with hands-on engagement, which made them feel more inspired by science. CARE-KNOW-DO resources with open schooling activities provided opportunities for students to take initiative and take responsibility as well as ownership of their process of learning. This finding suggested that students develop self-efficacy skills through interactions. Teachers play a key role by encouraging students’ interactions with family and science professionals through hands-on and real-life activities, which enhances students’ confidence and affective engagement.

Osborne et al. (2003) suggested that the promotion of favorable attitudes toward science, scientists and learning science has always been a key component of science education. Positive and inspiring interactions with formal educators (teachers), nonformal educators (scientists)
and informal educators (parents and community members) create opportunities for students to develop their interest in science and science-related activities, as well as in pursuing a career in science or science-related work. The findings of this study confirm that the positive interactions of students promote a positive attitude toward science by increasing their interest. Additionally, another contribution is independent thinking, hands-on engagement, and intrinsic motivation that can lead to “science is for me.”

4.5 Teachers’ views about how students learn about science

Teachers’ reflections revealed some key features about students’ perceptions of what learning means for them or in what ways they learn (epistemic beliefs). Teachers mentioned different...
approaches to learning in terms of how they learn. Their views about students’ approaches to learning science revolve around active engagement and problem solving, where the memorization of terms and equations is less favored. Learning science is seen as building a solid foundation through (Kang & Keinonen, 2018) inquiry-based activities. The CARE-KNOW-DO resources help students become more aware of what, how, and why they are learning and encourage understanding and communication, not just recall. Students are encouraged to attempt problem solving independently before seeking help. Teachers play a pivotal role in guiding students to interpret and respond to questions effectively. Conversations with students are considered essential in developing a better understanding of scientific concepts, and open schooling activities support the development of functional scientific literacy skills that are valuable in real-life situations. From the textual snapshots Table 6 about how students learn about science, six items emerged: (24) “Learning science is not about memorizing” terms and equations; (25) “Getting the correct answer is not more important than knowing how you got it”; (26) “Students should try to solve problems themselves first before asking for help”; (27) “Not all scientific questions have clear answers”; (28) “Discussions with my teacher and students help me understand science”; (29) “Students should have opportunities to learn science from others.”

The visual snapshots (Figure 10) highlighted three key pedagogical aspects related to students’ learning-to-learn process: (i) students self-monitoring their progress to avoid falling behind (ii) nurturing curiosity, resilience, creativity, questioning, and inquiry, enabling them to acquire knowledge and skills experientially and apply them across various contexts; and (iii) making their own learning decisions.

The overarching theme is independence, granting students the freedom to learn autonomously, exercise creativity, and chart their educational journeys while maintaining a sense of accountability for their progress. Students demonstrate their ability to construct concepts, foster

<table>
<thead>
<tr>
<th>Item</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>(24)</td>
<td>Solid foundation where youngsters have had the chance to build concepts through good inquiry-based activities. It’s a starting point for teachers to plan, to give them a better contextual flow so that students can see where the learning is leading to and in a way, it should prevent learning only to the test.</td>
</tr>
<tr>
<td>(25)</td>
<td>Therefore, we’re looking for a line of reasoning the students picked up that they wanted the rethink tasks to be, they wanted more support to understand why they got them wrong, rather than just thinking about what to do to understand it more.</td>
</tr>
<tr>
<td>(26)</td>
<td>Middle ability students were doing it in exams, they were doing it in ordinary tests, and it was just giving up if it got hard without trying to solve it. I gave them the mark scheme, I said you’ve got to be able to tell me why you got the question wrong and why you should get the correct answer.</td>
</tr>
<tr>
<td>(27)</td>
<td>They need to learn how to interpret what is requested and list the steps to prepare the response (...) when I was going round, I was discussing with the students, and with groups.</td>
</tr>
<tr>
<td>(28)</td>
<td>Teachers’ conversation with students is key to take that as part of developing the basic ideas “how can I link science to what I would understand and what would I make of it?”</td>
</tr>
<tr>
<td>(29)</td>
<td>I feel that real inquiry activities with family and experts truly help our young people develop what we might call functional scientific literacy, that are going to be useful to them outside of school</td>
</tr>
</tbody>
</table>
coherent understanding, and derive enjoyment from investigating and resolving errors. This finding suggested that teachers believe that students’ self-efficacy skills are honed through self-reflection and a deeper understanding of their learning process.

According to Osborne et al. (2003), effective teaching encompasses contextualizing content based on students’ experience and knowledge, involving students in goal setting, creating a supportive social environment for them, utilizing diverse teaching methods, and offering choices in engagement. Teachers should also consider students’ circumstances and adapt learning tasks. The study’s findings in the context of open schooling suggest pedagogical strategies that extend beyond contextual content teaching and involve students’ willingness, supportive feedback, exemplification, and personalized assistance. The findings emphasize that knowledge goes beyond content within context; students must build a solid knowledge foundation and move beyond surface-level understanding. It is about applying their understanding and taking purposeful actions; as one teacher noted, “How can I link science to what I would understand and what would I make of it?”

4.6 Teachers’ views about how students feel about science

The findings suggest that the CARE KNOW DO resources enhanced students’ positive engagement with science. Students eagerly anticipated science classes, embracing hands-on activities and an enjoyable learning environment. Teachers were motivated by their students’ enthusiasm and ability to connect science with real-life experiences. Open schooling provided students with opportunities to work on projects that addressed real-world problems and fostered a deeper interest in science and future aspirations. Students’ enjoyment and commitment positively influence their self-identity with science. Engaging students in science through open schooling activities is instrumental in developing their science skills and nurturing their interest, promoting awareness of diverse professional opportunities in the field. Six items emerged from the textual snapshots Table 7—how students feel about science. (30) “Learning science is enjoyable” for me. (31) “Science activities are fun.” (32) Learning science is not difficult (easy). (33) Students “do projects with others using science” to solve real-world issues. (34) I would like “to be seen as an expert in science.” (35) I would like to “have a job that uses science.”

From the reflective discussion, three strong aspects of pedagogical practices were identified and illustrated via visual snapshots (Figure 11).
These snapshots captured what was most valuable from teachers’ views in identifying and promoting affective engagement: (i) students were excited by school, wanted to keep learning fun; (ii) experienced a taste of success, which improved their self-esteem; and (iii) the way forward is toward independent learning. This points to how teachers can help students develop their self-concept (self-identity “science is for me”) through affective engagement.
As highlighted by Osborne et al. (2003), affective engagement is measured through the use of questionnaires that commonly consist of Likert-scale items where students are asked to respond to statements of the form. For example, Science is fun. I would enjoy being a scientist. Science makes me feel like I am lost in a jumble of numbers and words. This study has confirmed that and contributed to examining how teachers perceive that they are having fun, that they are showing that they are excited by school and what to keep learning, and that they want the opportunity to taste success and improve self-esteem.

### 4.7 Students’ science connection with deep fun

Findings from teachers’ qualitative data led to a diagram (Figure 12) showing pedagogical strategies that support students’ science connections with “deep fun.” Defined as students’ deep engagement and enjoyment in science, “deep fun” was observed through four strategies: real-life discussions leading to involvement, contextual knowledge expanding interest, applied knowledge generating enthusiasm, and scientific actions resulting in appreciation.

CARE-KNOW-DO nurtures science connections with deep fun through these strategies:

- Activate real-life discussions to foster curiosity and connect science to real-world issues.
- Acquire knowledge in context to build a strong foundation of understanding and skills.
- Apply knowledge in new situations to propose sustainable solutions and tackle challenges.
- Analyze scientific actions and the impacts of innovations to practice independent thinking.

These strategies lead to four outcomes:

1. **Students’ involvement** is observed when they actively and promptly engage in activities, showing curiosity and joy in their science learning. Discussing real-life issues that matter to them activates their motivation and enhances their willingness to engage in scientific discourse.

2. **Students’ interest** is manifested as sustained engagement and energy in learning activities. They feel “infused with science” as they immerse themselves and connect learning to their surroundings, building an understanding that helps them realize they truly “know science.”

3. **Students’ enthusiasm** is demonstrated by their confidence and excitement, along with the stamina to keep progressing. This is particularly noticeable when they master challenging tasks, translating learned knowledge into new problem-solving contexts. They feel accomplished in projects for sustainability by integrating the purpose and meaning of science.

4. **Students’ appreciation** is shown when they can think independently, design solutions, and make decisions using scientific principles. They enjoy fully understanding situations and take pride in initiating their actions, aiming to be recognized as science experts.

This approach enhances students’ connection to life through science and enriches the teaching experience, making learning and teaching a joyful, fun, and purposeful endeavor. A positive science connection, marked by meaningful enjoyment, was evident in both learning and teaching. Teachers valued enjoyable teaching, confident in its impact on students’ lives, especially when observing students’ enthusiasm and application of science to personal experiences. Teachers were motivated by students’ independent thinking and advanced reasoning. Anticipation and eagerness for future lessons enhanced teachers’ fulfillment, especially when struggling
students demonstrated clear understanding and engagement. Pride in fostering students’ autonomy and applying scientific knowledge in practical contexts deepened teachers’ satisfaction. This sense of fulfillment was tied to their hope that students remain engaged with science and prepared for advanced education, culminating in a deep sense of gratification and fun in their teaching roles. “Deep fun” enhanced both student learning and teaching. Teachers’ joy in observing students’ enthusiasm and application of science reinforced their own passion, creating a positive feedback loop that enriched the entire educational experience.

5 | “CONNECT-SCIENCE” QUESTIONNAIRE INSTRUMENT

The consensual qualitative analysis method (Hill, 2012) enabled rigorous development of quantitative measures from qualitative findings. The “CONNECT-science” questionnaire, shown in Table 8, was derived from a thematic analysis of 35 reflective statements about student learning from teachers’ insights (Almanasreh et al., 2019; Streiner, 2003). An independent panel of
<table>
<thead>
<tr>
<th>C1—Confidence and aspiration in science understanding (What I Know and What I Feel)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. I feel confident with my knowledge in science</td>
<td>0.791</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07. I feel confident talking about science</td>
<td>0.744</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06. I feel confident doing science projects with other people</td>
<td>0.726</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32. Learning science is easy</td>
<td>0.713</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35. I would like to have a job that uses science</td>
<td>0.661</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34. I would like to be seen as an expert in science</td>
<td>0.614</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>09. I feel confident using maths to solve problems in science</td>
<td>0.535</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C2—Fun participatory science with teachers, family and experts (Who I talk with/what I feel)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>20. My family thinks science is interesting (*)</td>
<td>0.711</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. My family thinks science will be important for my future (*)</td>
<td>0.708</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Science knowledge and skills can help me to get a job (*)</td>
<td>0.698</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. My teachers have explained the importance of science in my life and society (*)</td>
<td>0.647</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. My teacher encourages me to learn science (*)</td>
<td>0.625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Learning science will be useful in my daily life (*)</td>
<td>0.484</td>
<td>0.328</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. I know some people working with science to talk about what their jobs are like</td>
<td>0.347</td>
<td>0.467</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30. Learning science is enjoyable for me</td>
<td>0.442</td>
<td>0.457</td>
<td>0.317</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31. Science activities are fun</td>
<td>0.410</td>
<td>0.447</td>
<td>0.355</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C3—Active learning approaches in science (How I learn/know)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>27. Not all scientific questions have clear answers</td>
<td>0.665</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29. Students should have opportunities to learn from others (scientists, families, …)</td>
<td>0.650</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Discussions with my teacher and students help me understand science</td>
<td>0.406</td>
<td>0.597</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08. I feel confident using science to come up with questions and ideas</td>
<td>0.339</td>
<td>0.540</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. Students should try to solve problems themselves first before asking how to solve it.</td>
<td>0.491</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33. I would like to do projects with others using science to improve the world.</td>
<td>0.355</td>
<td>0.405</td>
<td>0.410</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C4—Involvement in-and-outside school science activities (what I do)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>02. I search for extra information related to science activities at home</td>
<td>0.726</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03. I read about science at home (web, news, books) (*)</td>
<td>0.716</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.673</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Continues)
5 experts and 10 science educators from Brazil and Europe, along with the author, rigorously validated the instrument (Appendix 1). They assessed content validity, ensuring relevance and representativeness, and face validity, confirming cultural appropriateness. In addition, the instrument underwent tests for acceptability, feasibility, length, and device compatibility via a preliminary pilot test, adhering to ethical standards and local regulations from five countries (AERA, APA, and NCME standards; Plake & Wise, 2014).

An optional open-ended question allowed students to share learning experiences with teachers, scientists, and family members. Translations followed International Test Commission guidelines (Hambleton & De Jong, 2003). Delivered via Qualtrics, the instrument used special coding for privacy and transparency, providing personalized feedback, open badges, and automated reports in six languages. This setup collected multilingual open data into a single database, ensuring methodological consistency under RRI and Open Science principles. The multilanguage CONNECT-science instrument provided just-in-time data, benefiting 2082 students aged 11–18 across five countries using CARE-KNOW-DO resources. This feature supports open science and responsible research, offering real-time insights and immediate educational impact. Questionnaire data, using a 1–5 Likert scale, were analyzed with SPSS version 24. Mixed methods validation ensured the instrument’s reflectiveness, comprehensibility, and translatability.

### 5.1 Exploratory factor analysis

Exploratory factor analysis (EFA) was used to test construct validity (Pett et al., 2003) with varimax rotation identified groupings among the instrument’s variables, resulting in 32 variables categorized into five components, as detailed in Table 8. Three negatively worded items were excluded due to poor loading: [15] Scientists work alone, [24] Learning science is about...
memorizing terms and equations, and [25] Getting the correct answer is more important than knowing how you got it. EFA was employed to ascertain the number of underlying factors, while subsequent CFA tested the consistency of item loadings across different countries within a cohesive model. A threshold above 0.3 for cross-loadings is commonly accepted in EFA (Shrestha, 2021). However, item 11 posed a unique case, showing a cross-loading of 0.370 on two factors: C1 (“What students know”) and C5 (“How students think”). To maintain balance in factor distribution, item 11 was retained in the “How students think” factor. This decision warrants further investigation with larger datasets to better understand the underlying structure. Consequently, our approach provides both transparency and a basis for future refinement in factor analysis. Cronbach’s alpha, with a value of 0.928, confirmed the reliability of the instrument, indicating a high degree of internal consistency (Cohen et al., 2007; Tavakol & Dennick, 2011).

The Kaiser–Meyer–Olkin measure yielded a value of 0.957, indicating that the sample size was sufficiently large for the analysis. Moreover, Bartlett’s test of sphericity produced a significant chi-square statistic of 136957.314, with 435 degrees of freedom and a $p$-value of less than 0.0001, affirming the appropriateness of the data for factor analysis.

The varimax-rotated factor analysis revealed six components, which integrate the 3 core constructs of CARE-KNOW-DO (Table 1) and 32 subconstructs (detailed in Table 8).

Each component represents a part of students’ science connection to life, showing how the CARE-KNOW-DO framework informs various aspects of “science capital” as follows.

**C1—Confidence and aspiration in science understanding (What I Know and What I Feel):** This combines students’ confidence in their knowledge about science and their feelings toward it. It reflects their self-efficacy and goals in science, showing their ability to use scientific knowledge for problem-solving and future careers. It aligns with science capital ideas like “Future Science Affinity” and “Self-efficacy in Science.”

**C2—Fun participatory science with teachers, family, and experts (Who I Talk With/What I Feel):** This involves students’ interactions with science and their enjoyment and interest in it. It highlights the importance of supportive relationships in learning science and aligns with science capital ideas like “Utility of Science Qualifications,” “Valuing Science and Scientists,” and “Parental Attitudes and Practices.”

**C3—Active learning approaches in science (How I Learn/Know):** This arises from how students approach learning science through inquiry and projects with others, such as scientists and community members. It reflects open schooling and aligns with science capital ideas like “Science Teachers and Lessons” and “Informal Science Activities.”

**C4—Involvement in-and-outside school science activities (What I Do):** This refers to students’ active participation in science-related activities both in school and outside. It relates to the science capital idea of “Valuing Science Experiences Outside School.”

**C5—Valuing science’s role to life and society (How I Think):** This is linked to students’ intellectual engagement with science and their ability to think scientifically with evidence-based skills. It reflects their understanding of science’s role in personal and societal well-being, corresponding with the science capital idea “Everyday Science Engagement.”

### 5.2 The suitability of representing 5 factors with EFA

In the present study, R statistical software (version 4.2.0) and the TAM package were used to determine whether five factors could be appropriately represented as underlying variables in
the data (Table 8). This was performed using a method called EFA along with the Rasch Rating Scale. The “item infit statistic” was used to evaluate the appropriateness of each item; a value between 0.5 and 1.5 is generally considered acceptable, although a narrower range of 0.7–1.3 is more stringent. The reliability of the instrument was assessed by the person separation index (PSI), which ranges from 0 to 1, where higher values indicate better reliability. Visual representations called Wright Maps were created to display the distribution of each factor. The results showed that all the items fell within the strict infit range, and the PSIs varied from 0.73 to 0.86, supporting the distinction of each factor as a separate underlying variable (see Appendix 3).

5.3 Confirmatory factor analysis

CFA was carried out using R statistical software (version 4.2.0) and the “lavaan” and “psych” packages to validate the model identified in EFA, which included 32 items across five factors, as shown in Table 2. Model fit statistics indicated the model’s goodness of fit (Jackson et al., 2009), and Cronbach’s alpha was used to assess the reliability of the factors.

The CFA yielded two absolute fit indices: RMSEA and SRMR. RMSEA values below 0.05, 0.08, and 0.10 suggest close, fair, and mediocre fit, respectively, according to MacCallum et al. (1996), while Hu and Bentler (1999) recommend an SRMR value below 0.08 for a good fit. The full data analysis showed an RMSEA of 0.066 (fair fit) and an SRMR of 0.063 (good fit), with Cronbach’s alpha ranging from 0.74 to 0.87, indicating good reliability.

CFA was also conducted for each of the five countries separately. For Spain (306 observations), the CFI and TLI were 0.742 and 0.718, the RMSEA was 0.080, and the SRMR was 0.077. The United Kingdom (277 observations) had a CFI and TLI of 0.856 and 0.843, an RMSEA of 0.066, and an SRMR of 0.058. For Brazil (751 observations), the CFI and TLI were 0.811 and 0.794, the RMSEA was 0.060, and the SRMR was 0.065. For Romania (343 observations), the CFI and TLI were 0.843 and 0.829, the RMSEA was 0.086, and the SRMR was 0.053. Greece (318 observations) had a CFI and TLI of 0.849 and 0.835, an RMSEA of 0.069, and an SRMR of 0.057. Cronbach’s alpha for these countries ranged from 0.50 to 0.92, reflecting varying degrees of reliability. In conclusion, the fit indices suggest that the EFA-derived model is suitably consistent for use in five individual countries.

5.4 Results from descriptive statistics

To compute an EFA using the SPSS component’s composite score from Likert data for each respondent, I multiplied each item score by its loading, summed these products, and divided by the total of the loadings. The weighted average, Scores C1–C5 = (item1 × loading1 + ... + itemN × loadingN)/(loading1 + ... + loadingN), reflects each item’s relative importance based on its loading. I used a threshold where scores over 3 indicated a positive connection (3.1–5) and then calculated the percentage for each component in Figure 13 per country, gender, and age.

I also determined students’ science connections by calculating a global weighted composite score. The weighted average score was calculated as (average score C1 × proportion variance C1 + ... + average score C5 × proportion variance C5)/sum of proportion variances. The overall score above threshold 3 refers to students connected with science (see Appendix 3).
5.5 Results about students' science connection across countries, gender, and age

Among the five countries, the mode age was calculated, and the number of students whose score were more than 3 to represent science connection.

Regarding age-related differences, science connections varied, with the highest rate of 78% in the 10–12 age group; this figure decreased to 72% among those aged 13–15 years and then slightly increased to 74% for those aged 16–15 years and 75% aged 17–18.

In terms of gender, 75% of male students demonstrated a marginally higher rate of science connection compared to 73% of female students. Only 56% of students who identified with a gender other than male or female reported feeling connected with science. As shown in Figure 13, this disparity is primarily due to reduced in-and-outside school science (16%) and fun participatory science with others (22%).

Despite this, more than half of the students (63%) reported feeling confident in their science abilities and recognized the importance of science.

Brazilian students with a modal age of 16 years and Spanish students with a modal age of 11 years lead in science connection, at 80 and 79% rates, followed by Romanian students with a modal age of 16 at 73%, Greek students with a modal age of 17 at 70%, and UK students with a modal age of 14 at 57%, which is the lowest. The majority of Brazilian, Spain and Romanian students regard science as valuable (c5 = 92%). In Brazil, open schooling with CARE-KNOW-DO resources has been particularly impactful, with the majority of Brazilians feeling very confident in science in terms of knowledge and aspiration (c1 = 93%), even though only 41% engage in science-related activities outside school with their families or with university support. Most students reported active learning experiences with problem solving (Spain = 91%, Romania = 83%, UK = 82%, Greece 81%) with the exception of Brazilian...

**FIGURE 13** CARE-KNOW-DO framework to strengthen science connection CCBY Okada.
students (56%). The United Kingdom, however, has the lowest overall science connection at 57%, with particularly low participation in-and-outside school science activities (“DO”) at only 10%.

5.6 Validation related to subconstructs—Questionnaire items

Descriptive statistics (Appendix 2.2 Students CONNECT-science data) about the whole dataset reveal that only 23% of the participants were uninterested in science careers. There were 47% who know science professionals to talk about what their jobs are like, 47% agreed that their family found science interesting, and 52% acknowledged its importance for their future. Learning science was enjoyable for 51% of the students; however, 56% still associated learning with memorization, and 43% focused on correct answers about conceptual understanding.

Less than half (44%) of the participants stated not doing science activities outside of school, but 49% engaged in scientific discussions at home. The importance of STEM skills is recognized by 73% of problem-solving students, 66% believe science contributes to making informed decisions, and 68% see its relevance to a happy, healthy life. A strong majority, 69%, feel capable of justifying their views with evidence.

5.7 Validation considering individual levels from a mixed method approach

Students were grouped by their connection to the subject: low (below 2.5) and high (above 3.5). To illustrate how individual learning cases can guide interventions, two examples related to rewilding resources (see Section 3.1) were selected, featuring girls from the United Kingdom in different educational stages.

In the Year 7 Biology class (ages 11–12), the lesson focused on an introduction to ecosystems, including simple food chains and basic ecological concepts such as habitats and biodiversity. Students also learn about the basic impacts of human activities on ecosystems.

In contrast, the Year 10 Biology class (ages 14–15) covers more advanced topics. Students explore complex ecosystem relationships, such as symbioses, competition, and predator–prey dynamics. They delve into detailed ecological concepts, including energy flow and nutrient cycles, and study the impact of human activities on ecosystems in depth, covering areas such as pollution and conservation efforts.

5.7.1 Students connected with science

Lara’s reflections on her experience completing the questionnaire showed that doing so helped her think more deeply about the value of science in her life and her learning experiences. She appreciated the opportunity to perform science projects that addressed real-world problems and that were relevant to her life. In her words, “I like doing projects about real problems that are useful in my life.” Lara also recognized the importance of independent thinking and collaboration in science and enjoyed discussing science ideas with others as active learners during open schooling activities. As she put it, “I liked thinking and talking with others instead of being told.”
Lara, a Year 7 student aged 12, female, reported feeling confident about doing science projects, talking about science with family, and using science to come up with questions and ideas with an expert. However, she lacked confidence in using math to solve problems in science. Lara strongly agreed that science, technology, and math are important for solving problems and that science helps people around the world lead happy, healthy lives. She believed that scientists need to use their imagination and typically work collaboratively. Additionally, Lara agreed that science helps people use information to make decisions and that learning science will be useful in her daily life. Her teacher encouraged her to learn science and explained the importance of science in her life and society. Lara believed that science knowledge will help her obtain a job, and she now knows professionals with whom she can discuss science-based careers. She agreed that discussions with her teacher and friends may help her understand science. However, Lara also believed that learning science involves memorization and that obtaining the correct answer is more important than knowing how she got it. Despite this, she believed that students should solve problems themselves before asking for help. When asked about her feelings toward science, Lara reported that science was easy, and she found science activities and learning science enjoyable. She expressed interest in doing more science projects with others and would like to be seen as a science expert, although she was uncertain whether she would like to have a job that uses science. Overall, Lara enjoyed her open schooling experience. Her response to the open question about whether she had any comments or questions was “I liked doing projects about real problems that are useful in my life. I liked thinking and talking with others instead of being told. I liked this questionnaire, asking me questions I've never thought about deeply.” Her total score on the CONNECT-science instrument was 3.5, with her scores for each of the five components being c1: 3.3, c2: 4.1, c3: 4.1, c4: 2.0, and c5: 3.60.

5.7.2 Students disconnected from science

Ana finds science boring and challenging, showing low self-efficacy and a negative self-concept in science. She is uncertain about using evidence, asking questions, solving problems, and working on collaborative projects. Ana’s family does not show much interest in science, and she feels unsupported by teachers and peers. She lacks enjoyment in science and has no interest in a science career.

Ana is a 15-year-old girl aged 10 years who does not often engage in science activities outside of school, such as reading, talking, asking questions, or searching for information. She lacks confidence in using evidence to justify her views and does not feel confident using science to come up with questions, ideas or solve problems in science with math. She is uncertain about collaborating with others in science projects. Although she agrees that learning science will be useful in her daily life, she is not sure if science helps people make decisions. She thinks that science, technology, and math are not important for solving problems, and she does not believe that science helps people around the world lead happy, healthy lives. Ana is not convinced that science knowledge and skills will help her obtain a job. Although
she agreed that her teacher encouraged her to learn science, she disagreed that the teacher explained the value of science in her life and society. She also disagrees that her family thinks science is interesting and strongly disagrees that science will be important to her future. Ana thinks that learning science is mostly about memorizing terms and equations and that obtaining the right answer is more important than understanding how to solve it. She is not sure whether students should try to solve problems themselves before asking for help. She strongly agreed that not all scientific questions had clear answers and that discussions with her teacher and other students did not help her understand of science. Finally, Ana neither agrees nor disagrees that science activities are fun. She strongly disagrees that learning science is easy and enjoyable, and she has no interest in being seen as an expert in science or having a job that uses science. When asked about her learning experience, Ana’s response to the open question was “Why do we have science almost every day, and why is it so difficult to understand?” Despite her low score (2.0) on the self-assessment, Ana’s responses provide some insights into identifying potential interventions, such as c4, that expand her interest in performing science activities beyond school and that help her with c5 valuing science based on her motivation and needs (c1: 2.3, c2: 2.3, c3: 2.6, c4: 1.0, and c5: 1.5).

These findings highlight the need for collaborative projects and discussions in science education supported by foundational knowledge, social and emotional engagement. EFA points to the importance of self-efficacy, self-concept, and support from family, teachers, and professionals in learning science. Both Ana’s and Lara’s beliefs view science learning as memorization, a part of traditional transmissive learning (Okada & Sheehy, 2020) aiming for grades and certificates, rather than an interactive path to deeper understanding. This negatively impacts their self-efficacy and self-concept in science. Supporting struggling students, such as low achievers, is crucial in open schooling activities. Inclusion, equity, and affective engagement are vital. A self-assessment questionnaire complemented by other tools helps teachers personalize support for students’ individual and group needs to enhance their learning and thinking skills, as highlighted in other studies (Okada, 2024; Okada et al., 2024).

6 | DISCUSSION

This study, grounded in a theoretical-empirical basis, delved deeper into the concept of science connection among disadvantaged students, detailing the development and validation of the CONNECT-SCIENCE questionnaire. This instrument, anchored in the CARE-KNOW-DO constructs, assessed students’ feelings, beliefs, and attitudes toward science, integrating emotional, intellectual, social, and agentic elements. The “Connect-Science” instrument, validated in five countries captures a wide range of student experiences across different cultural, gender, and age dimensions.

6.1 | Main predictors of students’ connections with science

This study makes an original contribution by conceptualizing and identifying five primary predictors of students’ science connection, pivotal for enhancing educational strategies and
engagement: (1) confidence and aspiration in science understanding; (2) fun participatory science with teachers, family, and experts; (3) active learning approaches in science education; (4) involvement in science-related in-and-outside school science activities; and (5) recognition of science's importance in life and society. These factors lay the groundwork for developing a nuanced analytical tool, empowering students to introspectively assess their connection to science. Such introspection is crucial for fostering a deeper understanding of science's role in decision-making, academic achievement, sustainable future planning, and career development. Additionally, the tool provides invaluable insights for schools and organizations at various levels, facilitating targeted interventions to enhance science engagement.

The study unveils minor gender differences in the impact of CARE-KNOW-DO-supported open schooling activities on fostering science connections, a significant finding as it echoes the challenges highlighted by recent studies in engaging girls in science (Zhang, 2021; Zhao et al., 2024). However, another noteworthy finding is the identified gap for nonbinary students, suggesting a broader issue of inclusivity in science education that warrants further exploration. Although the literature in this area is limited (Rende Mendoza & Johnson, 2024) related studies such as that by Kosciw et al. (2009) demonstrate that underserved students identifying as LGB experience significantly lower perceptions of school climate.

Regarding age differences, the study corroborates literature (Dewitt et al., 2014) by showing that students' connection with science tends to be high in primary school but decreases in secondary school, where curricula become more extensive and rigid. Yet, this study uniquely finds a resurgence in science connection at the upper secondary levels, indicating that efforts to rekindle students' connection to science can be particularly beneficial at this stage, aligning with findings that students aged 17/18 with high science capital are more likely to pursue post-compulsory STEM qualifications and routes (Moote et al., 2021).

Furthermore, the study sheds light on geographical and demographic disparities in science connection, with notable variations across countries. This underscores the importance of culturally adaptive educational programs and the necessity of understanding the unique challenges and opportunities within different educational systems. It revealed that, in most countries, between 57% and 80% of underserved students reported feeling a connection to science after participating in CARE-KNOW-DO activities. The strongest connections were observed in Brazil and Spain, with notable outcomes in Romania and Greece, contrasting with the United Kingdom. The findings starkly contrast with those of Archer et al. (2020), who reported that only 16% of UK students aged 14–19 were interested in science careers, alongside a worrying trend of diminishing diversity among those students.

Underserved students face numerous challenges, including a lack of family support and difficulties in seeking and interacting with scientists (Scogin & Stuessy, 2015). This disconnects between projects and experiences warrants further investigation, particularly to understand the reasons behind the low levels of science connection in the United Kingdom for students aged 13–15.

Despite the comprehensive analysis provided, the study acknowledges the limitation of its sample size and the need for a more extensive, diverse database to enable a deeper, intersectional analysis. Future research directions are suggested to explore the nuanced dynamics of science engagement across different populations more thoroughly.

By grounding the CARE-KNOW-DO approach in open science principles and aligning with the broader educational research community, this study contributes significantly to enhancing students' science connection. It offers a pathway toward more inclusive, engaging, and effective science education. As part of an ongoing international project aiming to reach a broad number
of schools, this study provides valuable insights for managers and leaders of international programs, researchers, and practitioners. With its extensive participant base, the study not only facilitates comparative studies (Fredricks & McColskey, 2012) but also supports the development of tailored interventions and culturally adaptive educational programs.

### 6.2 Motivation, interest, and intrinsic value of science

My study makes a significant contribution to the literature on science engagement by employing a nuanced exploration of motivation, interest, and intrinsic value in science. This exploration is supported by a comprehensive methodological approach that leverages the CARE-KNOW-DO model. This model serves as a conceptual framework to understand “science connection” from the perspectives of teachers—who design and evaluate learning outcomes—and students—as reflective learners who self-assess their learning experiences.

This study shows that “Deep engagement” in science merges cognitive efforts with an emotional journey, enhancing learning by connecting educational experiences to personal life and the broader world. Teachers and students emphasize the significance of integrating personal views and making informed learning choices (Crick, 2012; Pugh et al., 2017; Simms & Shanahan, 2024). The multidimensional nature of engagement—encompassing behavior, emotion, and cognition—underscores its complexity in science education (Fredricks et al., 2004; Klaver et al., 2023) connected to life and world.

Findings suggest that Epistemic emotions play a crucial role in science learning, intertwining curiosity, excitement, confusion, and surprise, which are often beneficial for learning, whereas boredom and frustration may prove detrimental (Vilhunen et al., 2023). A pedagogy of wonder demands a connection to the emotive embodiment of science as a uniquely human process that nurtures our intense need to know. This connection is vital in both formal settings (with teachers and peers) and informal settings (with parents, siblings, and neighbors). Awe, characterized in the literature as an emotion that facilitates learning and motivates an orientation toward something larger than oneself, frequently appears in scientists’ descriptions of their work. The experience of awe can lead to a deeper engagement with science (Avraamidou, 2020), encouraging learners to transcend their everyday concerns and connect with perspective-taking and righteous indignation (Davidson et al., 2020).

This emotional engagement is critical for fostering a lasting interest in science, tapping into the intrinsic motivation to explore and understand the world around us. Incorporating these emotions into science education aligns with the CARE-KNOW-DO model’s objectives, enabling educators to craft environments that stimulate both intellectual, social and emotional learning with wonder and awe. This approach not only enriches the learning experience but also cultivates a holistic understanding of science, deeply linking it to students’ lives and communities and transforming their perceptions and relationships with the subject.

In SSI-based teaching, students’ behaviors can be observed through their interactions and discussions about various sources of knowledge, including civic knowledge, practices, and democratic values (Chowdhury et al., 2020; Hodson, 2020). My findings reveal that in open schooling environments that utilize the CARE-KNOW-DO framework, students experience a transformative connection to science. This connection is characterized by involvement, pleasure, enthusiasm, and appreciation, stemming from autonomous self-development (Bruner, 1997; Reeve, 2012) and deep fun. This refers to fostering students’ own ability to think,
question, speak, (CARE about); investigate, intervene, and innovate around them (DO) connected with science learning to life (KNOW).

The study identifies a dichotomy in students’ perceptions of science learning: many value problem-solving and reflection before seeking help, while others view science primarily as memorization, relevant only for exams and not applicable to real life. This perception highlights a gap in science education, underscoring the need for approaches that foster real-world connections and applications, as the CARE-KNOW-DO model facilitates.

Employing CARE-KNOW-DO resources and the CONNECT-science self-assessment tool in schools shows significant potential to shift the educational focus from standardized testing to addressing real-world issues that matter to families, students, and communities. This shift necessitates a reevaluation of science teaching practices to make science education more inclusive, engaging, and attuned to societal needs while enhancing students’ sociopolitical consciousness (Jones & Burrell, 2022; Jones & Taylor, 2022).

The epistemological beliefs of students about how science is learned warrant further investigation. These beliefs shape students’ scientific identity through factors like competence/performance, interest, and external recognition (Guo et al., 2022). Students with more sophisticated epistemic beliefs and greater prior knowledge tend to produce arguments of better quality and greater diversity than those with less sophisticated beliefs and less prior knowledge (Baytelman & Constantinou, 2018).

Given the observed benefits of open schooling, I advocate for a reevaluation of science teaching practices to more closely align science education with students’ lives and real-world challenges. The study’s findings reveal that integrating open schooling through CARE-KNOW-DO activities promotes meaningful interactions to enhance real lifeworld promoting students’ interactions with community stakeholders, both within and beyond the school environment. This approach empowers young students to develop skills through engagement with people they will be encountering as adults in their future roles as responsible citizens and professionals, better preparing them for future challenges. This comprehensive approach highlighting the significance of epistemic emotions and students’ epistemological beliefs, not only aligns with the CARE-KNOW-DO model’s objectives but also marks a step toward a more engaging, inclusive, and relevant science curriculum. It emphasizes the necessity for a science education that goes beyond traditional boundaries, cultivating a sense of wonder and curiosity intimately connected to the students’ world and the future they will shape.

6.3 | Open schooling and acceleration of the 2030 SDGs

The concept of open schooling, which was not extensively explored since its inception in 2015, is highlighted in this study, underscoring the significant role of science connection, literacy, and capital in equipping students with the competencies to contribute to sustainable futures. The CONNECT-science instrument enabled examination of the benefits of open schooling and barriers, with recommendations for achieving inclusivity and sustainability.

This research suggested that a lack of science connection hinders the development of vital skills, leaving students disengaged and ill prepared to address challenges in a science-reliant society. Conversely, this study recommends a dynamic synergy between science connection, scientific literacy, and science capital to foster scientific understanding. This tripartite synergy—embodied in caring emotions, knowing with understanding, and actionable application—solidifies science connection, bolstering self-concepts rooted in student actions, interests, and
motivations. Science capital, akin to cultural capital but specific to science, enhances engagement and understanding in various contexts (Godec et al., 2018). Science literacy involves comprehending scientific concepts and processes for personal decision-making and societal participation. Science connection is how individuals relate to science at the personal, local, and global levels, considering its relevance to their lives and actions for life-change sustainability. These concepts are interrelated: a strong science connection can enhance science literacy, which in turn builds science capital. Findings through the CONNECT-science instrument exploring the European Union’s open schooling ethos to expedite the UN Agenda 2030 with CARE-KNOW-DO provides four sets of recommendations for the open schooling declaration:

1. **Expanding open schooling as a collaborative educational effort**: Bring together schools, universities, and civil society for authentic education; nurture students’ science connection to life for wellbeing and sustainability; and expand communities’ awareness of real-world issues, understanding of their needs, and capacity to take action.

2. **Fostering students’ autonomy and transversal skills**: Encourage students to discuss real-life problems and solutions with professionals and communities through fun participatory science methods; increase awareness of future-oriented careers; and develop transversal skills in authentic contexts using socioscientific thinking and interdisciplinary knowledge.

3. **Enhancing curriculum through real-world application**: Use the CARE-KNOW-DO model for students to co-create knowledge and practice skills relevant to them within science, arts, and humanities curricula; foster meaningful learning with real-world applications of science for deep understanding, and promote curiosity, ownership, and citizenship, enabling students to act responsibly with responsive actions.

4. **Empowering students with ownership and responsibility**: Expand open schooling partnerships for open democracy and social justice locally and globally; assist with personalized learning by considering students’ individual learning needs alongside families, experts, resources, and technologies; and help students develop a sense of belonging, enjoyment, and confidence in science for life through open schooling.

7 | **FINAL REMARKS**

This study explored the concept of science connection, leading to the creation, implementation, and evaluation of CONNECT-science, an open research questionnaire. This self-reported instrument enables students to reflect on how they connect science to their lives, society, practical applications, and sustainability. It encourages students to recognize their science connections both within and outside the classroom and helps educators assess educational methods and open schooling interventions to support students struggling with science, lacking confidence, or showing low engagement. Personalized learning informed by responses to CONNECT-science and aligned with the CARE-KNOW-DO framework may lead to more equitable experiences in open schooling.

Despite some limitations that call for further research, the instrument identifies areas for improvement and suggests ways to support science connection among students from diverse cultural, gender, and age backgrounds. Future studies could examine the links between science connection and learning outcomes, the nature of student-society interactions, and the effects of educational methods across various demographics. Additional analysis is needed to understand how new teachers might localize resources, and tools based on CONNECT-science feedback.
CONNECT-science has demonstrated the effectiveness of the CARE-KNOW-DO model and open schooling in fostering students’ science connection through open research. This approach goes beyond merely making research knowledge accessible within the scientific community. Here, open research involves actionable knowledge and just-in-time data, emphasizing transparency, collaboration, and real-time problem solving. It reports results to all participants and stakeholders throughout the research process so that practices and decision-making can be improved in real time.

This study began during the COVID-19 pandemic with contributions from 2082 underserved students from 2021 to 2022, leveraging the open research culture established in previous projects (weSPOT, ENGAGE). The CARE-KNOW-DO model has facilitated these efforts, empowering communities through real-life issues, supported by just-in-time feedback and open badges. This open research approach with CONNECT-science.net enabled it to reach 51,488 underserved students in 1283 schools, supported by 2317 teachers, 636 science professionals, 41,633 families, and 131 policymakers (Kolionis & Okada, 2024), leading to various other studies. Examples include transversal skills (e.g., Okada et al., 2024), health care (Malagrida et al., 2023), and environmental protection (Gorghiu et al., 2024), among others.

A key focus of this study is the role of open science, along with RRI, in promoting sustainable living and contributing to global sustainability goals. With this sense and intention, the results demonstrated that open schooling, supported by the CARE-KNOW-DO model, has the potential to strengthen students' connection to science.

By integrating the meaning and purpose of science into students' real-world experiences, the CARE-KNOW-DO model can empower them to transform knowledge into action on issues vital to the well-being of their lives, communities, and the planet. To this end, the CONNECT-science instrument helps policymakers, educators, and students identify factors that facilitate or hinder the science connection necessary for emotional, intellectual, social, and proactive engagement, supporting life-changing sustainability efforts for this generation and future ones.

ACKNOWLEDGMENTS

This open research study is part of the CONNECT project, funded by the European Union’s Horizon 2020 Research and Innovation Programme (grant No. 872814). Earlier phases were conducted during the ENGAGE project (grant No. 612269) and the WeSPOT project (grant No. 318499). Supported under the aegis of Responsible Research and Innovation—Open Science Education with and for Society, it also received backing from the Open University UK. The author is very grateful to Dr Tony Sherborne (Science Curriculum Development) for his significant contribution in developing the CARE-KNOW-DO open educational resources used by more than 60,000 students across the WeSPOT, ENGAGE, and CONNECT projects. Additionally, special thanks to the following experts for their valuable feedback: Jude Sanders and Gemma Young (Science Teacher Professional Training), Prof. Dr. Peter Gray (EU Policy and Evaluation), Prof. Dr. Kieron Sheehy (Innovative Pedagogies), Prof. Dr. Jane Seale (Education and Research), Prof. John Oates (Ethics), and Dr. Kaustubh Adhikari (Statistics). Thanks also to the large open schooling networks, including project leaders, teachers, students, and researchers who contributed to the ENGAGE, WeSPOT, and CONNECT projects. Finally, the author appreciates the insightful comments from the three reviewers of JRST.

ORCID
Alexandra Okada □ https://orcid.org/0000-0003-1572-5605
REFERENCES


SUPPORTING INFORMATION
Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Okada, A. (2024). A self-reported instrument to measure and foster students' science connection to life with the CARE-KNOW-DO model and open schooling for sustainability. Journal of Research in Science Teaching, 1–43. https://doi.org/10.1002/tea.21964