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Fostering Transversal Skills through Open Schooling with the CARE-KNOW-DO Framework for Sustainable Education

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Abstract: This large cross-national study investigates the development of transversal skills in the context of open schooling—an educational approach integrating schools, universities, and communities to address real-world challenges—through the CARE-KNOW-DO framework. Utilising a mixed-methods approach across five countries, this research employs a novel validated self-report instrument to evaluate the perceptions of 12,074 underserved students concerning their learning experiences in open schooling environments. An exploratory factor analysis enabled us to explore quantitative insight into students' skill development, while thematic analysis of 20 teachers' reports contributed qualitative depth. The study identified six critical transversal skills: self-initiative, problem-solving, emotional engagement, scientific citizenship, authentic learning, and future prospects. Significant geographic, gender, and age-related variations were found, with notable disparities in skill perceptions among nonbinary students, indicating the need for more inclusive educational support. All countries showed high levels of perceived transversal skills, with 83% of Greek and 80% of Brazilian students leading, compared to 64% in Romania and the UK, and 62% in Spain. Trends suggest secondary students exhibit stronger global citizenship and authentic learning, although they report less confidence in problem-solving and self-initiative than their primary counterparts. These findings, viewed alongside 12 teaching competencies revealed through thematic analysis, underscore the effectiveness of open schooling, which is underexplored, in fostering key skills and call for pedagogical innovations that integrate real-life issues into the curriculum. The study contributes to Agenda 2030—quality of education by demonstrating the real-world applicability of the CARE-KNOW-DO framework for educational practice and policy towards equity and sustainability. Our comparative analysis of transversal skill development across diverse student populations, as well as teaching competencies, further advances the discourse on improving 21st-century education.

Keywords: open schooling; CARE-KNOW-DO framework; transversal skills; teaching competencies; cross-national study

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1. Introduction

In the 21st century, the swift advancements of technology, global interconnectedness, and evolving economies have led to a reassessment of "transversal skills" for success in life and work [1]. These skills are known as "21st-century skills" and include critical thinking, creativity, teamwork, communication, and adaptability [2]. They also encompass key STEM skills such as problem-solving, innovation, self-management, and reflective thinking [3]. Transversal skills go beyond single fields, equipping individuals to thrive in diverse and ever-changing environments [4]. Global consensus is growing on the

importance of integrating practical skills in conjunction with knowledge, attitudes, and values into education as fundamental elements of schooling.

The emphasis on transversal skills reflects a broader understanding that success in the contemporary world relies not only on technical knowledge and expertise but also on the ability to think critically, solve complex problems, work collaboratively across cultural boundaries, and adapt to new situations [5]. As economies become more interconnected and workplaces become more collaborative, the demand for individuals who possess these versatile, cross-cutting skills has surged. This global shift towards valuing transversal skills marks a significant departure from traditional education models that prioritize rote learning and specialized knowledge, underscoring a universal movement towards preparing students for the multifaceted challenges of the 21st century [6].

The burgeoning importance of transversal skills is further underscored by their alignment with the United Nations Sustainable Development Goals (SDGs), which highlight the need for education systems to equip individuals with the necessary competencies to contribute to sustainable societies [7]. As such, transversal skills are vital not only for individual success but also for addressing global challenges related to a sustainable environment, economy, and society, making their development and assessment a priority for educators, policymakers, and stakeholders across the globe [8–10].

The concept of "open schooling" is designed to empower students through partnerships with educators, scientists, professionals, family members, and policymakers to address real-life challenges [11]. It is considered a new approach in education through a collective effort that values the cocreation of knowledge, the discussion of innovations rooted in scientific research, and the execution of actions targeted at local community development. Recognized as a pivotal strategy for aligning educational practices with the objectives of AGENDA 2030 [12], open schooling is instrumental in promoting well-being, sustainability, and the realization of a future that benefits all members of society [13].

The lack of empirical research on how to develop and evaluate broad skills through new methods such as open schooling, which combines formal and informal education, points to a notable research gap. This underscores the urgent need for additional investigation in this area to foster competences for lifelong learning [14,15] and sustainable competitiveness, social fairness, and resilience [16].

This paper seeks to address this shortfall by examining the potential of an open-schooling approach, which aims to help educators integrate the development of transversal skills supported by open-learning resources focused on real-life issues addressed through community–school–university partnerships, following the CARE-KNOW-DO framework [13,17].

This paper proposes a method based on self-reported instruments for underserved students and teachers to better inform educators and policymakers about learners' gains in terms of transversal skills and challenges in educational practices in open schooling, thus making a vital contribution to bridging the current research gap.

2. Transversal Skills in the Context of Open Schooling

2.1. What Is Open Schooling?

The term "open schooling" was formally introduced in the European Union's report titled "Science Education for Responsible Citizenship" in 2015 [11] in parallel with Agenda 2030, which included the Sustainable Development Goals (SDGs). Open schooling underscores the significance of all SDGs—including the 4th Quality of Education—with authentic contexts and the 17th SDG partnerships, especially among educational institutions, research and innovation organizations, families, universities, and the business sector. This collaboration is essential for facilitating students' engagement with real-life projects, thereby enriching their learning experiences [13,14].

Hazelkorn et al. [11] elaborate on this concept, describing "open schooling" as a paradigm in which educational institutions, in concert with various stakeholders, emerge as catalysts for community well-being. The model encourages families to actively participate

in the educational process and engage as genuine partners in school activities. Moreover, it calls for the involvement of professionals from the business sector, scientific communities, civil society, and broader community in integrating real-life projects into educational settings, thereby fostering a practical and immersive learning environment.

The necessity for open schooling was articulated by an expert panel in response to Europe's declining number of individuals proficient in scientific knowledge at various societal levels. This challenge is not confined to Europe alone but is observed across different continents [15]. Governments are thus tasked with the crucial objective of nurturing a scientifically literate populace through a continuum of meaningful learning experiences accessible to all. In supporting the ethos of Responsible Research and Innovation (RRI), which advocates for science that is conducted "with", "for", and "by" society, there is an additional imperative to augment the cadre of responsible scientists and citizens dedicated to fostering desirable futures with healthy lives for a more socially, economically, and environmentally sustainable planet [16].

As highlighted by the definition of open schooling in the report on *Science Education for Responsible Citizenship* [12], scientific thinking fostered by science education should be seen as an essential component of compulsory education for all students. Fostering scientific literacy is crucial for addressing global challenges such as economic inequality; trust erosion; and technological disruptions, such as misinformation and privacy issues [17]. This statement underscores the need for policies that facilitate access to science education and provide equitable opportunities for excellence in learning outcomes [18,19]. It emphasizes the importance of engaging students, teachers, parents, and the wider community in scientific discourse, thereby ensuring that learners, both young and adult, are adequately prepared to pursue further studies in science education and actively engage in scientific discussions.

This study proposes a novel relationship between open-schooling and transversal skills [20], viewing them as synergistic and mutually reinforcing pedagogical strategies to enhance 21st-century education [21] and sustainability [22] underlined as follows. Open schooling, as a pedagogical approach, emphasizes collaborative, real-world learning experiences that extend beyond traditional classroom boundaries to include families, communities, professionals, and policymakers in the educational process [23]. This model facilitates the integration of students into meaningful projects that address genuine community challenges, thereby creating a rich learning environment where transversal skills can be developed and applied [24]. On the other hand, transversal skills facilitate open schooling because they equip learners with the ability to tackle complex, transdisciplinary issues [25] by learning to think critically, solve real-life problems creatively, communicate effectively, collaborate with others, and adapt to changing situations and technologies [26], which make up a core aspect of open schooling within a rapidly evolving global landscape that is heavily influenced by scientific and technological advancements. Table 1 presents the relationship between transversal skills and open schooling.

Table 1. Relationship between the transversal skills and open schooling. Source Okada (2024) CCBY [26].

Transversal Skills	Open Schooling	Learning Objective
Contextual Learning	Real-life projects offer authentic contexts for learning	Content in context helps students to see the relevance of their education to the outside world, enhancing their motivation and engagement
Collaboration and Communication	Students work with a diverse people, including peers, teachers, scientists, professionals, and family members	Students work in diverse teams and communicating ideas effectively
Problem-Solving and Critical Thinking	Real-life challenges require science to develop with and for society solutions	Students analyze issues, consider multiple perspectives, and develop strategies to address these challenges

Table 1. *Cont.*

Transversal Skills	Open Schooling	Learning Objective
Creativity and Innovation	Open schooling encourages exploration and experimentation in learning and fosters creativity and innovation	Students are engaged to develop novel solutions to the problems they are working to solve, thereby cultivating a mindset that values innovation.
Lifelong Learning and Adaptability	Open-schooling projects expose students to the continuous evolution of knowledge and the need for adaptability	Students learn the importance of being adaptable and of having anticipation and responsiveness in a rapidly changing world

In this study, open schooling is considered a powerful catalyst for the development of transversal skills to empower students and their school and community with a dynamic, real-world learning environment. The CARE-KNOW-DO framework presented in the following section aims to facilitate this process.

2.2. The CARE-KNOW-DO Framework

The CARE-KNOW-DO framework aims at integrating real-life problems into learning, encouraging students to engage (CARE) with significant issues, understand (KNOW) them through curriculum-based knowledge, and take action (DO), using their insights, for sustainable solutions. Table 2 shows how these elements interrelate and contribute to fostering transversal skills.

Table 2. Relationships between the transversal skills and the CARE-KNOW-DO framework. Source Okada (2024) [26] CCBY.

	Characteristics	Transversal Skills
CARE	Emphasizes the development of emotional intelligence, empathy, and ethical understanding. It is about nurturing a sense of responsibility, compassion, and care for others and the planet.	Students practice attitudes and values necessary for scientific citizenship and affective engagement.
KNOW	Focuses on the cognitive aspect of learning, encompassing the construction of knowledge, including the understanding of global challenges, sustainability, and the SDGs.	Students use knowledge to discuss solutions and practice critical thinking and problem-solving.
DO	Highlights the importance of collaboration and an active role to make a positive impact on their communities, translating what has been learned into practical in real-world actions.	Students contribute to sustainable development through positive interactions with scientists, teachers, and families toward sustainable development, which enhances self-initiative, authentic learning, and future prospects.

This model not only aims to make science education more relevant and engaging but also supports problem-based learning and socioscientific inquiry within a structured three-phase approach. It is designed to foster students' self-efficacy and active participation in sciences connected to RRI principles, such as diversity and inclusion, anticipation and reflectivity, responsiveness and adaptive change, and openness and transparency [27,28].

The CARE-KNOW-DO framework [15,16,26] fosters transversal skills in the context of open schooling and aims to provide a holistic approach to education that aligns with the needs of a sustainable future. This framework emphasizes the importance of not only academic knowledge but also emotional intelligence and practical skills to prepare students for the challenges of the 21st century. The relationship among CARE, KNOW, and DO encapsulates a comprehensive educational philosophy that seeks to cultivate well-rounded individuals. The relationships among CARE, KNOW, and DO are synergistic. CARE cultivates emotional and ethical foundations, motivating students to learn (KNOW) and apply (DO) their knowledge and skills in meaningful ways. KNOW provides intellectual substance, equipping students with the understanding necessary to navigate complex issues.

Finally, DO encapsulates the application of both emotional intelligence and knowledge, enabling students to act effectively and responsibly.

This integrated approach ensures that students are not only academically competent but also emotionally intelligent and practically skilled and ready to face the challenges of the future with empathy, knowledge, and action. In the context of open schooling, the CARE-KNOW-DO framework aligns with the goals of providing an education that is both comprehensive and adaptable, preparing students to thrive in an interconnected and ever-changing world.

2.3. Research Questions

This cross-national mixed-method study supported by formative, shared and coassessment [29] focuses on two sets of questions to explore transversal skills in the context of open schooling.

- RQ1. What are students' perceptions related to their learning experiences in terms of gains with open-schooling resources underpinned by the CARE-KNOW-DO framework across five countries? Are there any variations across countries, ages, and cultural differences?
- RQ2. What are the teachers' views about open-schooling teaching practices in terms of outcomes supported by CARE-KNOW-DO pedagogical resources faced across five countries? What were the challenges and strategies faced by teachers?

3. Methodology: Mixed-Methods Study

The CONNECT project, funded by the EU's Horizon Europe Programme, aims to enhance science education in secondary schools through inclusive open-schooling focused on underserved students. It integrates science action into the curriculum, involves the community, and addresses the lack of "science capital" among students. By providing real-world challenges, support from scientists, family activities, and inclusive teaching strategies, CONNECT inspires students to connect science to their lives and society and increase interest in science careers for sustainable development.

Figure 1 displays the locations of the students who participated in the project, used open-schooling resources, completed real-life issue activities related to the SDGs, and provided data about their experience for this study [30].

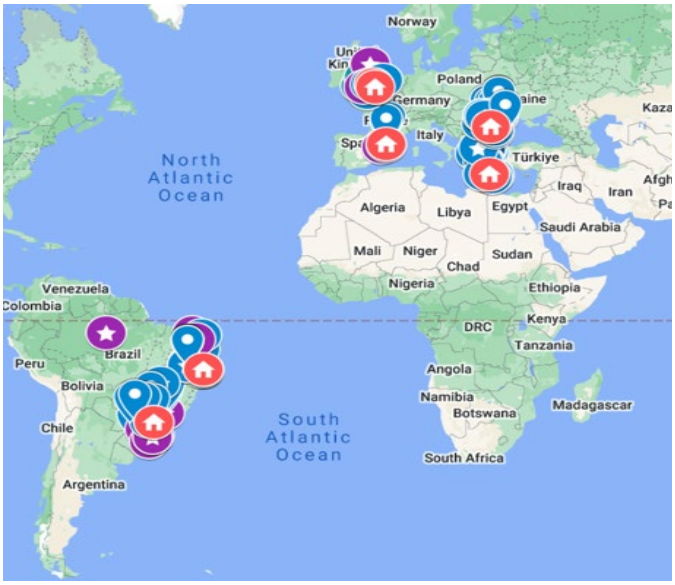

Figure 1. CONNECT network map of open-schooling research schools. Source: Okada et.al. (2023) CCBY [23]. Icons in red refers to hubs, icons in blue refers to large communities and icons in purple refers to new initiatives. 2023).

The CONNECT platform integrates three multilanguage digital systems. The languages presented were Catalan and Spanish, English, Greek, Portuguese, and Romanian. The three digital systems for designing, implementing, generating, and sharing open-schooling practices and results underpinned by the CARE-NOW-DO framework were as follows:

1. **The CONNECT project website** in WordPress showcases a multilanguage repository of open-schooling practices reported by teachers with examples developed by their students. These best practices showcase the open-schooling outcomes reported by educators through interviews and focus groups, using a template.
2. **The CONNECT open-schooling platform** in WordPress provides more than 70 open-schooling resources in different languages for multiple actors participating in the activities (teachers, students, scientists, and families). It also offers an open-schooling community group area for each school, organization, and community or network to interact and to design, implement, and disseminate open-schooling practices.
3. **The CONNECT self-reported instrument** in the Qualtrics mobile app was used for students and educators to provide their views about their open-schooling experiences. This app also provides an open badge and self-automated reports.

The subsequent sections present the open-schooling resources, participants, research instruments, and data-generation processes.

3.1. Open-Schooling Resources Underpinned by CARE-KNOW-DO

The CONNECT project team produced 70 open-schooling resources [31,32] underpinned by the CARE-KNOW-DO framework. Table 3 shows a sample.

Table 3. A sample of examples of open-schooling resources based on CARE-KNOW-DO.

Name; (SDGs)	CARE	KNOW	DO
Healthy minds; (SDG-3) health	Students identify their needs regarding mental health and physical and social well-being.	Students learn how to design an action plan with their families and mental health professionals.	Students implement their personalized actions plans and disseminate the results.
Energy-savers; (SDG-7) affordable and clean energy	Students help an entrepreneur fund the development of a new energy saving device.	Students learn about renewable energy, solar panel, and energy transfer in physics	Students create a crowd-funding campaign including the benefits of the energy saving device.
Creating and Using Maps; (SDG-11) sustainable cities and communities	Students use mapping skills to solve a spatial problem that they face in their daily life.	Students learn about mapping techniques and sustainability issues through science in society	Students create a digital map from scratch present solutions and present recommendations to their local community.
Machine learning to protect forests, (SDG-12) life on land	Students raise awareness about the destruction of forests due to illegal activities	Students learn about AI learning machine, image recognition and processing, and programming and ethics.	Students create a scratch program for image recognition with photos captured via a drone.
Carbon-neutral; (SDG-13) climate action	Students help a café to become carbon-neutral by reducing carbon emissions and offsetting.	Students learn about climate change, carbon emissions, and global warming.	Students act as climate-action consultants and create recommendations to reduce carbon emissions.
Microplastics; (SDG-14) Life in water	Students convince people how they can best reduce their contribution to microplastic pollution and why they should.	Students learn about particle model and mixtures in chemistry, including the size and scale of small particles in mathematics.	Students act as environmental entrepreneurs, producing a filter to reduce microplastics in the water, supported by their family and a professional.
Rewilding; (SDG-15) life on land	Students and community discuss which animal should be rewilded in their national park.	Students learn about food webs and competition, biodiversity, and balancing ecosystems.	Students act as environmental activists, map pros and cons, and create a campaign with fun to enhance biodiversity.

The selection of issues underpinned by CARE-KNOW-DO and integrated into school curricula was guided by several criteria:

- It includes a balance of personal, community, and global issues, each with local relevance for youth.
- It is an appeal to a diversity of students in terms of gender, age, and culture, informed by research such as the "Relevance of Science Education" and through consultations with students, paying special attention to disadvantaged students.
- Desirable future scenarios linked to the curriculum are also relevant to scientists, educators, and researchers.

3.2. Participants' Profiles

The CONNECT project aims to support students from underserved communities, especially those from low socioeconomic backgrounds. This target group includes public schools with a high percentage of students benefiting from free meals or scholarships for food located in disadvantaged neighborhoods and students with limited access to digital technology and the internet. The project also focuses on students whose parents do not work in science-related fields. Ethical approval was obtained in each participating country, with consent forms, informational materials, and evaluation instruments translated into the local language for teachers, students, and parents, who contributed on a voluntary basis. All the data generated by the participants were codified to ensure privacy.

The quantitative data were generated by 12,074 students aged 7-to-19 years who completed the self-assessment. This group constituted a portion of the 16,787 participants who engaged in open-schooling activities, with some unable to finish the assessment due to internet-connectivity issues. The students represented a range of educational levels, from primary through tertiary, and were distributed geographically with the following representation: 4% from Catalonia, Spain; 7% from the UK; 15% from Romania; 23% from Southern Brazil; 26% from Central Brazil; and 26% from Greece. Notably, 95% of the participants came from underserved backgrounds and attended state schools. With only 17% having parents working in science-related fields, there was an indication of lower science engagement outside of school. While 68% had access to the mobile internet, a significant number still lacked access to personal computing devices at home.

Qualitative data were generated by 1392 teachers who participated in the CONNECT project and who supported diverse student groups with various resources and a self-assessment instrument. These teachers were distributed as follows: 86 from Catalonia, 172 from the UK, 211 from Romania, 376 from Greece, and 548 from Brazil, spanning the northeast, south, north, and southeast regions, respectively. Most of them worked in public schools, serving low-income families, with 73% being female. They taught a range of subjects, from biology to computer science, while 30% covered disciplines such as geography, arts, and languages. From this group, 111 teachers provided detailed reports on open-schooling practices, using a template (Appendix B) that included sections on learning gains. This subset included 11 from the UK, 11 from Spain, 20 from Romania, 27 from Brazil, and 42 from Greece. The analysis concentrated on the experiences of four teachers from different educational levels and disciplines in each of these five countries, focusing on transversal skills, challenges, and strategies. This approach yielded 20 case studies that offer insights into teaching practices and outcomes, further enriched with interviews.

3.3. Procedures

Figure 2 shows a flowchart outlining the data-generation process, which was designed to prevent cognitive overload. It details the roles of school or science heads, science teachers, and students, all supported by a CONNECT project partner.

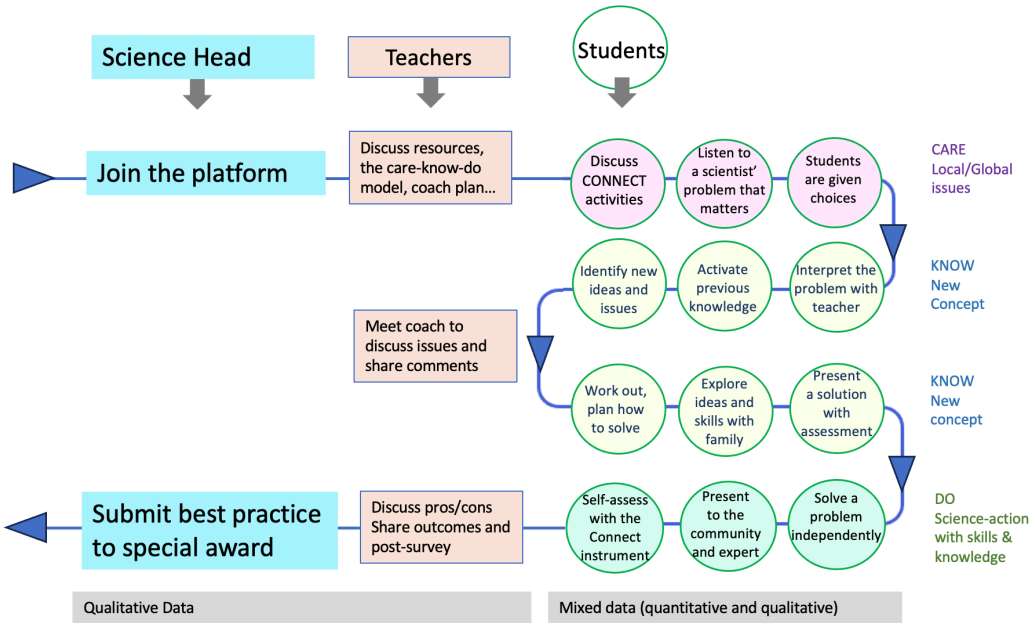

Figure 2. CONNECT workflow for implementing research-based open schooling. Source: Okada (2024) CCBY [30].

Each group—school or science head, teachers, and students—follows specific steps to contribute to the main aim: hands-on science learning and making a difference in the community.

- **School Leaders**: They start by connecting with a CONNECT partner and signing up on its platform. They complete a survey and discuss what their school needs and wants to achieve.
- **Science Teachers**: They begin by talking about CONNECT's resources and how to do open schooling with a mentor. They plan how to use learning materials and methods and receive guidance during the project. Afterward, they review what worked well or did not, completing a survey to share their thoughts.
- **Students**: They go through steps that involve them actively in learning, starting with exploring CONNECT's activities. They engage in identifying and solving real-world problems with guidance from teachers and input from scientists and their families. The journey ends by presenting their solutions to experts, earning a recognition badge, and applying what they have learned in a practical project, reflecting on the CARE-KNOW-DO approach.

3.4. Research Instruments

The CONNECT instrument for students (Figure 3)—an app for mobile phones, tablets, and computers—comprises a 30-item self-reported multilanguage instrument with feedback and an open badge (Figure 3; see also Appendix A).

It was validated by a panel of educators from the UK, Greece, Romania, Spain, and Brazil. They assessed content and face validity, as well as construct validity, through an exploratory factor analysis (EFA), per Pett et al., 2003 [33]. This process conformed to ethical standards and local regulations according to the AERA, APA, and NCME guidelines based on the work of Plake and Wise (2014) [34]. The instrument also includes an optional set of open-ended questions for qualitative depth, adhered to translation standards set by the International Test Commission according to Hambleton et al. (2003) and was developed using the Qualtrics multiple languages and cultures platform [35].

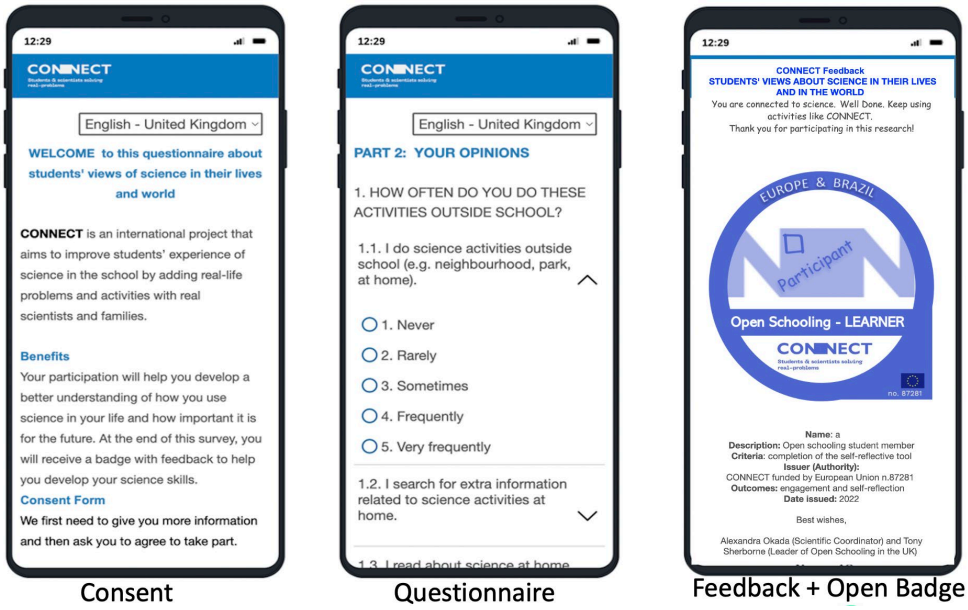

Figure 3. Multilanguage self-report instrument with open badges and automated support. Source: Okada (2023) CCBY [30].

Teachers also reported their open-schooling experience using the CONNECT open-schooling practices and a template. They described their teaching practices supported by CARE-KNOW-DO, including challenges and strategies (Figure 4; see Appendix B). This template enabled them to record and display their methods and student achievements, supplemented with photographic evidence. Translation into 5 languages and ethical approval for data generation were secured by five countries involved in the implementation. The data generated and the tools used were designed to support openscience principles, offering feedback in students' native languages. The synthesized reports with just-in-time feedback were also made accessible for all partners and schools. The report offered critical insights to educators and policymakers.

Figure 4 shows the platform, which includes resources such as "rewilding", which involves reintroducing animals to their natural habitat. It features a template for teachers to describe and reflect on their practices (Appendix B) with a coach's guidance, alongside examples of work performed individually and in groups generated by students and analyzed and evaluated by teachers. The figure highlights, for example, student-created argumentative maps focusing on the rewilding of wolves as a means to enhance biodiversity in national parks. These maps detail the role of wolves as apex predators, their ecosystem impacts, and the historical decline in wolf populations due to human activities. By using color-coded connectors and causal language, the maps visually demonstrate the complex relationships between environmental benefits and rewilding challenges. The students' analysis evaluates the potential effects on ecosystem services and biodiversity, with AI mapping tools facilitating the visualization of both supporting and counterarguments. This approach allows for a comprehensive exploration of different perspectives, helping students reflect on, build on, and explain different informed views on the issue.

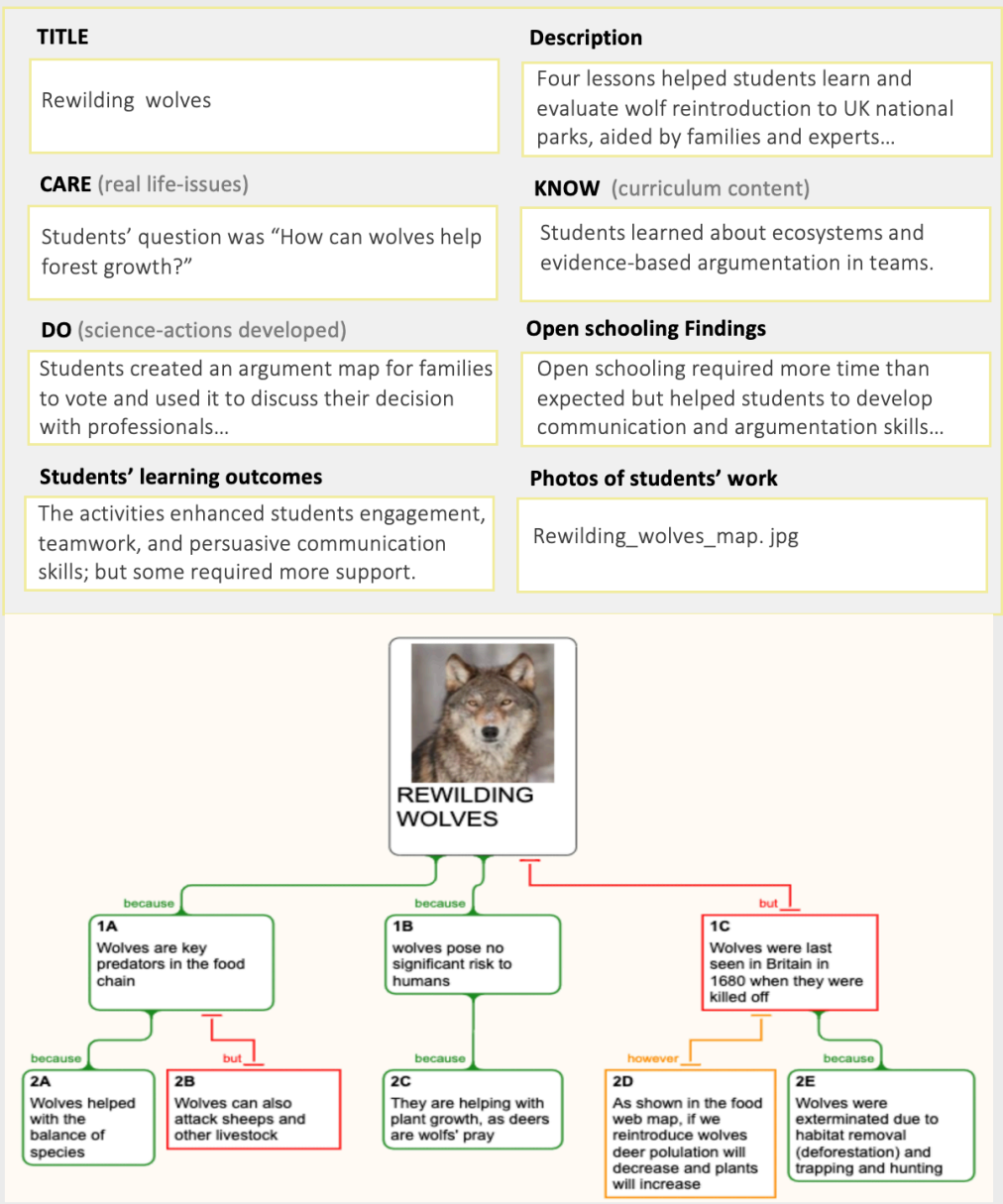

Figure 4. Multilingual qualitative template for describing open schooling practices: a teacher's guide with a student-developed argument map example. Source: Okada (2023) CCBY [23].

4. Findings

4.1. RQ1—Students' Views about Their Learning Experience with Open Schooling

This study' 12,074 contains complete responses from a total of 16,787 students, spanning diverse countries, ages, and genders, lends solid credibility to our analysis (Table 4).

Table 4. Exploratory factor analysis—Varimax; See Appendix A.

Description	C1	C2	C3	C4	C5	C6
C1. Transversal skill: Problem-solving						
07. I feel confident talking about science.	0.68					
10. I feel confident with my knowledge in science.	0.68					
11. I know how to justify my views using arguments and evidence (facts or data).	0.67					
09. I feel confident using maths to solve problems in science.	0.67					
08. I feel confident using science to come up with questions and ideas.	0.65					
06. I feel confident doing science projects with other people.	0.62					
C2. Transversal skill: Self-initiative						
02. I search for extra information related to science activities at home.		0.73				
04. I talk about real-life problems to learn science.		0.71				
03. I read about science at home (web, news, books).		0.70				
01. I do science activities outside school (e.g., neighbourhood, park, at home).		0.66				
05. I ask interesting questions to learn science.		0.66				
C3. Transversal skill: Affective engagement						
34. I would like to be seen as an expert in science.			0.69			
35. I would like a job that uses science.			0.67			
32. Learning science is easy.			0.61			
31. Science activities are fun.			0.59			
30. Learning science is enjoyable for me.			0.56			
33. I would like to do projects with others using science to improve the world.			0.52			
C4. Transversal skill: Scientific citizenship						
13. Science, technology and maths are important for solving problems.				0.72		
12. Science helps people around the world to lead pleasant, healthy lives.				0.69		
16. Knowing science helps people to make decisions using information.				0.64		
17. Learning science will be useful in my daily life.				0.53		
14. Scientists need to use their imagination to solve problems.				0.50		
C5. Transversal skill: Authentic learning						
23. My teacher encourages me to keep learning science.					0.73	
22. My teachers have explained the importance of science in my life and society.					0.72	
28. Discussions with my teacher and students help me understand science.					0.60	
29. Students should have opportunities to learn science with others (scientists, families. . .).					0.50	
C6. Transversal skill: Future prospects						
21. My family thinks science will be important for my future.						0.71
20. My family thinks science is interesting.						0.63
19. Science knowledge and skills will help me to get a job.						0.59
18. I know some people working with science to talk about what their jobs are like.						0.54

However, we acknowledge that excluding the 4713 participants who did not complete all questions is a limitation potentially affecting the breadth of our exploratory factor analysis (EFA).

Data from the questionnaire, rated on a 1–5 Likert scale, were analyzed with SPSS version 24. The instrument's reliability was confirmed by a Cronbach's alpha of 0.929, indicating strong internal consistency [36]. The KMO measure was 0.957, and the significant Bartlett's test of sphericity (chi-square = 136,957.314, df. = 435, and Sig. = 0.000) strongly indicates that a factor analysis is appropriate for the dataset, as there is enough evidence of underlying patterns or factors within the variables that can be extracted and analyzed [37].

The results of the EFA with Varimax rotation identified six comprehensive skill components, each comprising a group of specific skill items that collectively form the six transversal skills in open-schooling education (Table 4). These components are (c1) problem-solving, (c2) self-initiative, (c3) affective engagement, (c4) scientific citizenship, (c5) authentic learning, and (c6) future prospects.

These components comprehensively cover the spectrum of skills and attitudes critical for engaging with and understanding open-schooling learning experiences related to science for a sustainable life and sustainable future, spanning from personal efficacy and emotional investment to societal implications and future orientations. Each component (C1 to C6) had strong loadings on its respective factors, typically above 0.5, which indicates a good association with the factor; communalities for each item were reasonably high, above 0.3; and scree plots were used to validate the number of factors extracted. The 56% total variance explained by the EFA indicates a moderate and meaningful representation of the transversal skills model through six components, serving as a solid foundation for deeper analysis and practical implementation in this study [38].

C1. Problem-solving: This component highlights individuals' confidence and ability to utilize scientific knowledge and mathematical skills to solve problems, support arguments with evidence, and participate actively in scientific discussions.
C2. Self-initiative: This component focuses on students' proactive behavior in seeking science knowledge and engaging in science-related activities beyond formal education and showcases their autonomy and initiative in their learning journey.
C3. Affective engagement: This component addresses the emotional connection students have with science, including their intrinsic motivation, their enjoyment, fun, interest, and the value they place on science for personal and societal benefit, driving their sustained interest and participation in science.
C4. Scientific citizenship: This component emphasizes the importance of understanding science's role in society and everyday life, promoting informed citizenship and recognizing scientific literacy as essential for making responsible decisions.
C5. Authentic learning: This component concentrates on the social aspects of science learning, including the significance of teacher-student interactions and collaborative learning environments, highlighting communication and cooperation in science education.
C6. Future prospects: This component combines a forward-looking view of science's relevance to future careers with an engaged learning approach that values family influence and interaction with science professionals, fostering a comprehensive and open attitude towards science education and its opportunities.

To compute an EFA using the SPSS component's composite score from Likert data for each respondent, each item score was multiplied by its loading, summed for these products, and divided by the total of the loadings. The weighted average, Score C1 = (item1 $\times$ loading1 + . . . + itemN $\times$ loadingN)/(loading1 + . . . + loadingN), reflects each item's relative importance based on its loading. A threshold was used where scores over 3 indicated a positive connection (3.5 to 5), and then the percentage of each component per country, gender, and age was calculated.

To determine students' learning gains in terms of transversal skills, a global weighted composite score was calculated. This was performed by taking the sum of each component's average score multiplied by its proportion variance (for components C1 through C5) and then dividing by the sum of the proportion variances. A score above the threshold of 3 indicates that students have an overall positive perception of their transversal skills.

Results about Students' Perceptions Related to Transversal Skills across Countries, Gender, and Age

Among the five countries, we calculated the number of students whose scores were more than 3 to represent transversal-skills confidence.

The highest levels of perceived transversal skills were observed in 83% of the Greek students, followed by 80% of the Brazilian students. In Romania and the UK, the percentage was 64%, with that in Spain being slightly lower, at 62%. These findings suggest that the CARE-KNOW-DO framework is effective in supporting underserved students' positive perceptions of transversal skills based on self-assessment questionnaires of their learning through open-schooling activities.

Age-related differences revealed variation in perceptions of transversal skills, with the highest percentages observed in the 10–12 age group at 80% and in the 13–14 age group at 79%. The figure decreased to 55% among 15-to-16-year-olds before experiencing a slight increase to 57% in the 17-to-19-year-old group.

Gender differences showed that 82% of female students had slightly greater perceptions of transversal skills than did 79% of male students. This percentage decreased to 67% among students who identified with a gender other than male or female. As illustrated in Figure 5, the disparity is evident across all skills, with a difference of approximately 45%, except for authentic learning, which stands at 66%.

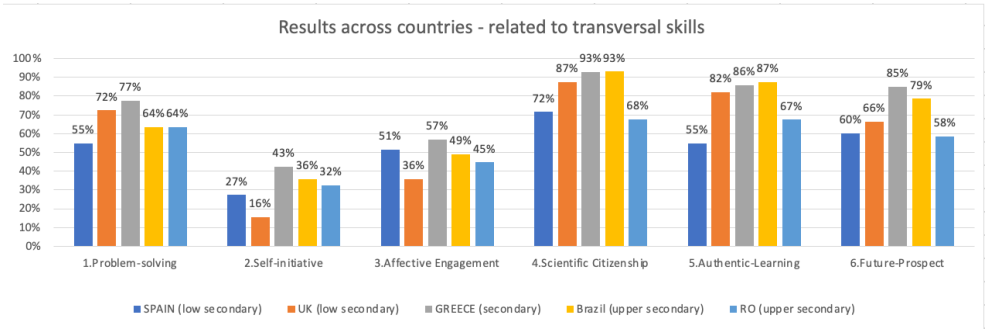

Figure 5. Students' science connections across countries.

Figure 5 presents a detailed description of transversal skill component variations for comparative analysis in terms of geographical, gender, and age differences.

Each bar chart uses a variety of colors to represent six transversal skills: problem-solving, self-initiative, engagement, scientific citizenship, authentic learning, and future prospects.

Countries: Among the countries listed (Spain, Greece, the UK, Brazil, and Romania), Figure 5 shows notable variations. Brazil shows the highest percentages for scientific citizenship and authentic learning, while Greece leads in self-initiative. Brazil and Greece lead in scientific citizenship and authentic learning; Greece also leads in self-initiative. Meanwhile, the UK shows the least self-initiative. Although Spain has lower rates for problem-solving and self-initiative, it has higher rates for scientific citizenship. Each country exhibits distinct profiles in these skills.

Age: Figure 6 breaks down the perceptions by age group (10–12, 13–14, 15–16, and 17–18). The variance is very small across ages for almost all skills. All age groups show the lowest percentage for self-initiative learning but have relatively high percentages for authentic learning and scientific citizenship. Younger students (aged 10–12) had the highest percentage of confidence in problem-solving. There is a trend toward a small increase in the perception of skills related to scientific citizenship and self-initiative from low secondary school to upper secondary school across ages. However, perceptions related to problem-solving and affective engagement seem to decrease slightly from primary to middle secondary school years (ages 10–12 vs. 15–16).

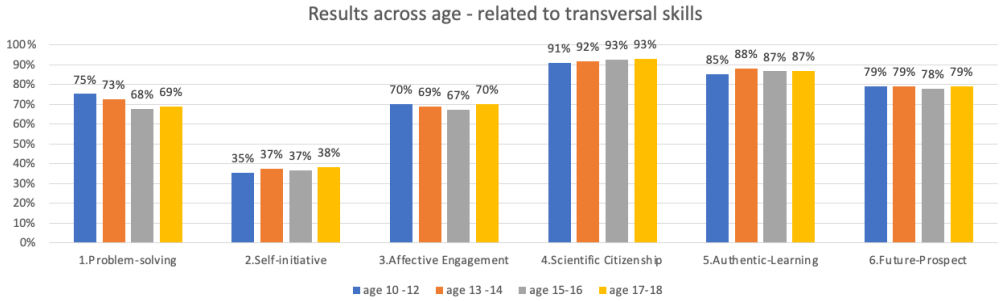

Figure 6. Students' science connections across ages.

Gender: Figure 7 divides perceptions by gender (female, male, and other). Female students show higher percentages of scientific citizenship and authentic learning, while male students show higher percentages of problem-solving. The percentage of students who identified as "other" was lower in all categories than in females and males.

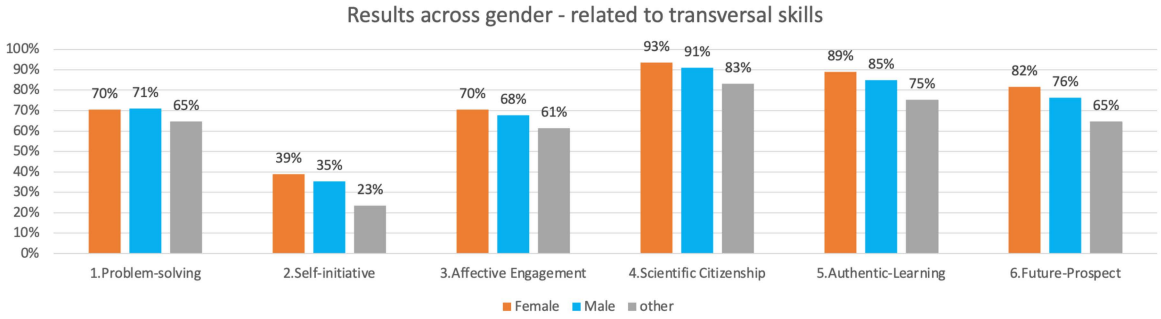

Figure 7. Students' science connections across genders.

Overall, there are distinct differences in the perceptions of transversal skills when dissected by country, age, and gender, indicating that these factors may influence how students relate to and develop these skills within the context of open schooling.

In all examined countries, the percentage of students demonstrating self-initiative in science was relatively low, with 8% in the UK, 15% in Spain, 21% in Romania and Brazil, and 29% in Greece. This suggests that a limited number of students are proactive in their science learning and skill development outside of school. Conversely, a high percentage of students across these countries are developing scientific citizenship skills, with Brazil leading at 85%, followed by Greece at 83%, Spain at 72%, the UK at 69%, and Romania at 62%. These figures indicate that open schooling may have a significant positive impact on fostering scientific citizenship. This trend is closely mirrored in the areas of authentic learning and future prospects. Apart from self-initiative skills, problem-solving emerges as another challenging skill, with engagement levels ranging from Spain's lowest, at approximately 40%, to Greece's highest, at 60%. Problem-solving is one of the key transversal skills, with half of the students feeling confident—60% in Greece, 56% in the UK, and 54% in Romania, followed by 44% in Brazil and 39% in Spain.

4.2. RQ2. Teachers' Views on Challenges and Drivers of Open-Schooling Practices

To address this question, we employed a thematic analysis [39] to examine 20 teachers' self-reported practices, including students' learning achievements, difficulties, and pedagogical outcomes, in terms of the benefits and challenges associated with the open-schooling approach. (Table 5).

Table 5. Teaching Competencies, Challenges and Strategies.

Teaching Competencies	Challenges	Strategies
Facilitating decision-making skills via teamwork and resources	Students require skills for effective decision-making	Enhancing problem-solving abilities with the use of interactive videos and strategic teamwork
Fostering equity in problem-solving through interactive discussions	Addressing the diverse needs of students with varying abilities	Conducting group discussions complemented by video resources to improve problem-solving skills
Engaging learners to be proactive in learning and mentorship	Students struggle with lack of understanding	Inviting expert peers or alumni to provide clarity and contextual understanding
Exploring unfamiliar topics by using emerging technologies	Overcoming initial disengagement with unknown topics	Empowering students through curiosity-driven, hands-on activities and the integration of emerging technologies
Maximizing impact through student-led innovations	Maximizing interaction with families and experts	Engaging students as policymakers, implementing real innovations to address actual problems
Sustaining student motivation by diversifying teaching techniques	Keeping students engaged and motivated	Implementing a range of teaching techniques, including both individual and group discussions
Personalizing learning to enhance scientific citizenship	Differentiating instruction to support diverse students' abilities	Providing personalized support and highlighting practical applications for scientific citizenship
Overcoming the lack of access to experts through virtual interactions	Limited interaction with science experts for additional insight	Facilitating access to experts and employing technology for effective virtual interactions
Facilitating curriculum pressures with support and flexibility	Managing curricula pressure and lack of relevance	Adapting the activities and reworking the curriculum plan to open up opportunities for open schooling
Employing the CARE-KNOW-DO framework, managing time issues	Allocating time for collaboration among learners, families, and experts	Utilizing the CARE-KNOW-DO model to address real-life challenges, reassess plans, and increase engagement
Promoting connections between the curriculum and future vision	Creating relevant activities for effective teaching and learning	Aligning open-schooling initiatives with the curriculum by mapping common issues and a vision for the future
Facilitating real-world projects and ensuring successful outcomes	Integrating practical projects into the students' schedule	Tailoring activities to ensure curriculum compatibility and engaging students for successful outcomes

This sample included four teachers from different educational levels and disciplines in each of the five countries. To present the analysis, we selected representative distinctive snapshots according to each of the six specific transversal skills, also considering findings provided by students in terms of achievements and difficulties. To code the database, a qualitative codebook was developed that enables the identification of key teaching competencies with open schooling to foster transversal skills.

C1.Problem-solving: To address challenges in problem-solving within STEM, educators have identified critical obstacles, such as students' difficulties with complex tasks and insufficient skills for decision-making. Research underscores that these deficits can undermine confidence and hinder performance. Recognizing the skills gap is crucial. This study revealed that heightened awareness for both educators and students is important for implementing targeted support and interventions to bolster students' problem-solving abilities, such as teamwork, with suitable roles and meaningful discussions using personalized resources, thereby enhancing their STEM educational outcomes. This approach empha-

sizes the importance of tailored support to bridge this gap and improve problem-solving proficiency in STEM fields (Table 6).

Table 6. Teaching Snapshots Related to Problem-Solving.

Primary School	**Challenge: Decision-Making Abilities**	**Strategy: Strategic Teamwork with Roles**
Teacher Year 6 from Romania (Rewilding)	*"The activity was framed in the curriculum but it was very challenging with complex activities that highlighted their abilities and required them to make decisions".*	*"Participation in group activities was beneficial as it led to an enhancement in students' confidence and self-esteem through engaging in challenges where roles were appropriately assigned".*
Secondary School	**Challenge: Varying Abilities Students**	**Strategy: Discussion with Video Resources**
Math and Chemistry Teachers Year 8 from UK (Microplastics)	*"The resources were good but they required some customization to be truly ready for the classroom, to fully meet the diverse needs of students with varying abilities".*	*"We had some great group discussions and problem-solving sessions focused on capturing microplastics. The lesson saw high engagement, particularly in response to the videos about microplastics and in group work where students designed their solutions".*

C2.Self-Initiative: Teachers reported that challenges such as unfamiliar topics can reduce student initiative, but targeted support and experiential learning can enhance their motivation and curiosity to increase their participation. Additionally, a lack of understanding about open-schooling activities is a concern that can be mitigated by employing peer learning and mentorship to inspire students, boost confidence, and cultivate a supportive community that encourages proactive engagement. Encouraging students to take initiative in their STEM education with practical applications of STEM concepts can empower them to become future leaders in STEM fields and bridge the gap between classroom learning and real-world challenges (Table 7).

Table 7. Teaching Snapshots Related to Self-Initiative.

Primary School	**Challenge: Lack of Understanding**	**Strategy: Peer Learning and Mentorship**
Teacher Year 5 from Catalunya (Mental Health)	*"Students had problems because they did not understand what was being asked. They had difficulties to develop the activities".*	*"They needed someone specialized in mental health to explain well what was being asked. A former student came to explain her work".*
Secondary School	**Challenge: Unknown Topic**	**Strategy: Emerging Tools for Empowerment**
Computer Science Teacher Year 11, from Greece (AI)	*"Initially, students were not engaged, the activity about forest fire detection with AI was an unknown topic for them".*	*"A key strategy was to foster students' curiosity with hands-on activities, using drones and developing a code to detect forest fires with AI".*

C3. Affective Engagement: The challenges and strategies highlighted by teachers indicated the importance of fostering affective engagement in STEM education through meaningful, collaborative projects that empower students to make a difference in their communities. By providing opportunities for students to explore, create, and contribute positively to society, educators can inspire a lasting passion for STEM subjects and cultivate a sense of purpose and agency among learners. Collaboration, discussion, and ongoing engagement are important for preventing disengagement or burnout (Table 8).

Table 8. Teaching Snapshots Related to Affective Engagement.

Primary School	**Challenge: Maximizing Impact**	**Strategy: Children as Policymaker**
Teacher Year 6 from Brazil (Urban Forest)	*"The open schooling approach presented no significant challenges. Children developed a project aimed at protecting the animals of an urban forest. They interacted with their families, zoo professionals and local policy managers".*	*"A significant outcome was the children's proposal of a new traffic regulation to protect animals from driving accidents, which was subsequently implemented in the city. It profoundly impacted the children, instilling in them a joy, fun, and appreciation for science as a tool for decision-making and effecting change in the city".*
Secondary School	**Challenge: Maintaining Motivation**	**Strategy: Diversifying Techniques**
Chemistry Teacher Year 13, from Spain (Mental Health)	*"Students are conducting thorough reviews on mental health topics and thereby recognizing problems and opportunities in myriad categories. While personal involvement can be demanding, maintaining motivation throughout the participatory revival process poses a greater challenge".*	*"The essential practice of small-group individual training will precede a phase where problems are shared among class groups and families for the remainder of the year, fostering a broader dialogue".*

C4.Scientific Citizenship: Teachers expressed a need for access to science experts. Collaborating with science experts can enrich classroom experiences and provide students with real-world perspectives for appreciating science with and for society. Another issue is that students vary in their ability to present claims supported by evidence. By addressing challenges related to differentiation, support, access to expertise, and family involvement, educators can promote scientific citizenship among students by nurturing their critical thinking skills, scientific literacy, and ability to apply scientific knowledge to real-world issues. These strategies help cultivate a sense of responsibility and active participation in scientific inquiry for sustainable development among learners (Table 9).

Table 9. Teaching Snapshots Related to Scientific Citizenship.

Low Secondary	**Challenge: Scientific Thinking**	**Strategy: Assistance and Practical Application**
A Biology teacher, Year 7, UK (Rewilding)	*"Students showed satisfaction with their research, analysis, and presentation tasks. However, some lower-ability students struggled with distinguishing a scientific question from a claim, suggesting the need for additional support in data analysis Differentiation for lower-ability students was another challenge".*	*"While some students demonstrated confidence in presenting claims supported by evidence, others required further assistance. The initiative successfully enhanced students' interest, fun and confidence in science, with students acknowledging the relevance of science in their daily lives and expressing enjoyment in learning. Students displayed critical thinking skills in evaluating the pros and cons of their decisions, utilizing theory in their decision-making processes".*
Secondary School	**Challenge: Lack of Experts**	**Strategy: Flexible Community Interaction**
Chemistry Teacher Year 13, from Spain (Mental Health)	*"It would have helped us if we had been provided with the contact of an expert".*	*"We modified the activities to adapt them to our needs and join activities to make the session more agile and simplify the objectives. The students discussed five factors that affect mental health with the family".*

C5. Authentic Learning: Teachers explained that authentic learning with open schooling is challenging. Due to scheduling constraints, students had limited time to work with extra activities. The pressures of the curriculum, difficulty managing time, and weak relationships between the curriculum and real-life issues also posed challenges for teachers. Continuous efforts by teachers are vital for innovating their practices despite curriculum limitations. By addressing challenges related to limited time and curriculum limitations, educators can create engaging and effective learning experiences that support students' academic development and prepare them to shape a better future (Table 10).

Table 10. Teaching Snapshots Related to Authentic Learning.

Primary School	**Challenge: Curriculum Pressure**	**Strategy: Constant Work**
Science teacher, Year 6, Catalunya, Catalunya	*"The challenges for us were pressure of the curriculum, difficulted time management, and no strong relationship between curriculum with mental health".*	*"The strategy that supported the process was the constant work of teachers".*
Secondary School	**Challenge: Limited Time**	**Strategy: Revised Plan**
Computer Science Teacher, Year 10, from Greece	*"A significant challenge was the limited time students had to work with their parents, as they all needed to be at home simultaneously. The students were lacking in many basic knowledge areas and skills due to the quarantine in previous years. Therefore, in the program, the activities extended beyond the planned duration, and initially, there was a problem with coordination and cooperation".*	*"The CARE-KNOW-DO program has increasingly attracted the interest of more students and has also promoted parental engagement. Conversations between students, teachers, and parents, which focused on the students' needs, were useful because they addressed relevant issues linked to the curriculum".*

C6.Future Prospects: A barrier highlighted by teachers was that open-schooling activities could be perceived as irrelevant by others not directly involved in the curriculum. Another issue is extra activities beyond *students' already demanding school schedules*. Establishing partnerships with university students and professors in vulnerable communities poses another challenge. However, connecting extracurricular activities to the formal curriculum and developing strategic partnerships can help ensure the sustainability and effectiveness of these initiatives (Table 11).

Table 11. Teaching Snapshots Related to Future Prospects.

Low Secondary School	**Challenge: Curriculum Connection**	**Strategy: Building a Vision of the Future**
Teachers in biology, arts, language, physics, chemistry, Year 7, Paraná, Brazil	*"Open Schooling activities can be considered by teachers not part of the curriculum, and not relevant for them. In addition, integrating university students and professors with vulnerable communities might be challenging".*	*"A strategy for implementing open schooling and establishing partnerships was mapping a common problem and building a vision of the future. Open schooling provided a collaborative and cocreative process for students to facilitate explaining complex content for vulnerable communities, visualizing data, drawing projects, registering a system of ideas, and sensitizing persons to become changemakers".*
Upper Secondary School	**Challenge: Demanding School Schedules**	**Strategy: Involvement and Growing Interest**
A Physics Teacher, Year 11, Female, Motru, Romania	*"Integrating these CARE-KNOW-DO activities with the school curriculum was well planned and structured, though the main challenge was conducting them in addition to the students' already demanding school schedules".*	*"Working in groups, they delivered reasoned presentations comparing the use of green energy to traditional energy, and discussed classic* versus *electric mobility. The students' involvement and growing interest led to the successful achievement of the objectives outlined in the activity plan, as well as a shift in their perspectives and attitudes towards green energy".*

5. Discussion

This research examined the impact of open-schooling practices utilizing a cross-national mixed-method methodological approach [40] and anchored in the CARE-KNOW-DO framework [17]. Initially, we employed a multilanguage, semi-structured instrument

validated through exploratory factorial analysis [38] to explore students' gains in transversal skills [4] within various geographical contexts and across different age groups and genders. This mixed-methods study also examined teachers' pedagogical perspectives on the challenges and strategies associated with supporting students' learning gains in terms of transversal skills through this educational approach to inform practitioners and policymakers [41,42].

This study reveals six pivotal components that enrich science education with open schooling for sustainable futures, illustrating a comprehensive hexagon model (see figure abstract). This model is divided into two triads for individuals and groups, each emphasizing the core principles of care-know-do.

The **first triad** focuses on skills to support individuals during their own process of learning:

- **Care (affective engagement):** This variable reflects the emotional investment in learning, driving motivation and connection to the subject matter.
- **Know (problem-solving):** This component highlights cognitive skills essential for understanding and addressing complex issues.
- **Do (Self-Initiative):** This study underscores the importance of active engagement and the willingness to take initiative in learning processes.

The **second triad** transitions to key skills relevant for groups amplifying the social aspect of learning:

- **Care (future prospects):** Finally, "care" projects emotional and ethical considerations of future societal impacts and personal growth.
- **Know (authentic learning):** This extends "know" to encompass real-world problem-solving, connecting classroom learning to external environments.
- **Do (scientific citizenship):** Here, "do" evolves into fostering a sense of responsibility and participation in scientific practices within society.

This hexagonal framework not only deepens our understanding of the dynamic interplay between individual and collective learning experiences but also underscores the significance of integrating transversal skills [3,6] through open schooling. By blending significant findings with actionable insights, our study illuminates the pathways towards fostering a robust scientific mindset and competencies among students and teachers alike. The CARE-KNOW-DO model thus serves as a blueprint for nurturing the cognitive, social, and emotional skills essential for navigating and contributing to a sustainable future.

Practically, these components highlight the critical need for real-world applicability in science education, guiding curriculum design and educator development towards more impactful and meaningful student experiences, both individually and globally. Furthermore, this cross-national approach aims to bolster diversity, inclusivity, and knowledge exchange, promoting a global scientific citizenship that embraces a multitude of perspectives and cultural insights [36] in science.

Over 60% of underserved students in Spain, the UK, and Romania and over 80% in Brazil and Greece reported a positive perception of their development in areas related to scientific literacy, authentic learning, and future opportunities. This reflects the success of the CARE-KNOW-DO framework in facilitating the development of open schooling internationally and bolstering underserved students' confidence in their transversal skills supported by teachers from various disciplines and professionals in the sciences, particularly within the social triad of skills, which is essential to open schooling. Our research findings are in accordance with the Eurydice report (2012) [41], which underscores the importance of transversal skills in enriching interdisciplinary learning and fostering active engagement in collaborative processes, particularly emphasizing interpersonal competencies such as communication and teamwork within educational settings. Furthermore, a novel discovery from our study reveals that implementing open schooling through CARE-KNOW-DO activities facilitates meaningful interactions for young learners with community stakeholders both within and outside the school environment. This approach enables students to

cultivate transversal skills by engaging with individuals they are likely to encounter in their future roles as responsible citizens and professionals, thereby equipping them more effectively for the challenges ahead.

The comparative analysis of this study emphasizes how cultural and educational systems play a critical role in addressing challenges in key skill areas such as problem-solving, affective engagement, and self-initiative. These areas benefit from personalized support, and more research is required for effective solutions. Age-related data show a decrease in perceived skills such as self-initiative skills among older students, highlighting the need for stage-appropriate educational interventions [42,43]. A gender analysis revealed the benefits of open schooling across genders, but nonbinary students experienced less positivity, indicating the need for inclusive practices that support all students' self-efficacy [43].

The Eurydice report (2012) [41] also emphasizes the critical role of student participation in developing transversal skills, such as decision-making (aligned with problem-solving), self-regulation (related to self-initiative), and inspired participation (tied to affective engagement). Our cross-national study underscores the importance of this triad of skills for personal development, necessitating additional support. Another original finding of this study is that the individual triad of transversal skills is more challenging to foster than the social triad. However, our findings from teachers' perceptions indicate that student involvement in decision-making, when supported by reflective and interdisciplinary activities, significantly nurtures these skills. This is further enhanced by pedagogical strategies that include personalized support, interactive and experiential learning, fostering curiosity, incorporating real-life innovations and challenges, and instilling a vision for the future. Such teaching strategies lead to advancements in self-management, well-being strategies, and the promotion of equality and sustainability initiatives. They also cultivate critical thinking, problem-solving capabilities, and intrapersonal skills—all of which are vital for holistic development on a global education scale [42].

This study introduces an innovative framework comprising twelve teaching competencies, making a significant contribution to the domain of open schooling. This framework delineates the requisite skills for enhancing both individual and collaborative learning. It not only outlines these competencies but also identifies the associated challenges and proposes strategies to address them. Table 4 effectively illustrates this model, providing a thorough guide for advancing open-schooling practices and the cultivation of transversal skills. For instance, the development of problem-solving skills requires teaching approaches that are tailored to the diversity of learners, fostering interactive discussions and offering customized resources. The enhancement of self-initiated skills involves adopting innovative methods to nurture independence, particularly when students demonstrate a lack of understanding. Affective engagement skills can be amplified through personalized learning experiences that convert challenges into opportunities for cognitive and emotional involvement. Challenges such as limited access to experts hinder the cultivation of scientific citizenship skills, underscoring the necessity for professional engagement and flexible learning environments. Authentic learning skills are constrained by rigid curricula and limited time, necessitating the integration of practical, hands-on projects. The pressures of curricula also impact Future Prospects Skills, which require learning experiences that are both relevant and aligned with educational standards. Addressing these challenges demands creative and adaptable educational strategies to effectively integrate transversal skills into the fabric of education.

The study's findings provide actionable insights for practitioners and policymakers in the participating countries. For example, the European year of skills [43], featuring various curriculum reforms, presents an opportunity to contribute to and extend this research. **Brazil**'s curriculum reforms initiative [44] underscores "life projects" to enhance transversal competencies, employability, and career guidance. **Greece**'s Skills Laboratories [45,46] in primary and secondary education focus on cultivating modern skills, including life and digital competencies. Romania's New Education project [47] aims for technological and societal advancement through comprehensive educational reform. This includes

institutional restructuring, curricular updates, and the integration of digital technology, positioning **Romania** to meet European Union educational standards and paving the way for a forward-thinking approach to open schooling. In the **UK,** the "Sustainability and Climate Change" strategy [48,49] aims to incorporate awareness across educational services, presenting an additional avenue for open schooling to contribute to environmental sustainability and further emphasizing the importance of transversal skills in addressing societal challenges and emerging technologies.

Rooted in RRI and open science methodologies [50,51], our study aims to deepen the understanding of transversal skill development within innovative educational models, such as open schooling, in both formal and informal settings to empower underserved students [52,53]. The cross-national mixed-methods approach is especially beneficial for globally oriented projects. Despite the inherent limitations of self-assessment tools commonly employed in such studies, our research advocates for a broader spectrum of evaluative instruments and a more inclusive participant base, with a particular focus on underserved learners. This inclusive approach is designed to facilitate more extensive comparative and intersectional analyses, accentuating the need for context-specific educational strategies that improve learning outcomes universally.

6. Final Remarks

This study contributes significantly to the discourse on transversal skills by highlighting the pivotal role of open schooling in preparing underserved students for future challenges. This underscores the necessity for personalized support and curricular adaptability, which are identified as essential for education in the 21st century. Our findings indicate a greater awareness among students of the value of scientific literacy and its potential to drive global change, an increase from what was observed in the PISA 2018 results [54,55].

Open schooling is presented as a transformative educational model that aligns with Agenda 2030's objectives [56], advocating for scalable and sustainable evidence-based practices. It addresses the need for career awareness as the workforce undergoes transformative changes and considers the long-term impacts on society [57,58].

This study underlines the necessity for educational frameworks that are adaptable, inclusive, and responsive, fostering the equitable development [59] of digital skills [60,61] and sustainability competencies that are critical for shaping inclusive and desirable futures [62–64]. The CARE-KNOW-DO framework is well positioned to support such educational efforts to enhance students' connection to science [65]. For practitioners, this research provides practical recommendations for enhancing pedagogical flexibility and employing diverse teaching strategies, including the incorporation of real-life challenges into the curriculum for authentic learning experiences for young people as future professionals [66] and lifelong learners [67]. The insights from this research set the stage for further investigations into innovative educational practices, such as open schooling [66], which are essential for fostering strategic transversal skill development [67]. Applying these insights supported by the open schooling declaration [68] to current educational systems will enable stakeholders to more effectively cultivate these skills in students, preparing them for the complexities of today's global environment and contributing to the advancement of educational research.

Author Contributions: A.O. played a pivotal role in designing the study, developing the evaluation instruments and applications, and writing the manuscript. All coauthors collaborated to create open-schooling resources, guided by the CARE-KNOW-DO framework, to deliver teacher training and to collect and interpret data within their respective countries. Additionally, all coauthors contributed to the revision of the final draft of the manuscript. All coauthors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Human Research Ethics Committees in the UK, Greece, Romania, Spain, and Brazil.

Informed Consent Statement: Informed consent was obtained from all participants of the study.

Data Availability Statement: Data available via Open Research Data Online for publication (https://ordo.open.ac.uk/projects/CONNECT_-_Inclusive_open_schooling_with_future_oriented_science/125821, accessed on 3 March 2024). **Translated versions of this article were prepared by coauthors to inform their national networks.** Greek: https://oro.open.ac.uk/96442; accessed on 25 March 2024. Romanian: https://oro.open.ac.uk/96571; accessed on 25 March 2024. Portuguese: https://oro.open.ac.uk/96573; accessed on 25 March 2024. Spanish: https://oro.open.ac.uk/96574; accessed on 25 March 2024. **Open Schooling Declaration**: https://bit.ly/osd2024; accessed on 25 March 2024. **Videoclip related to this article:** https://www.youtube.com/watch?v=LrwRX1aO2Kk; accessed on 25 March 2024. **Questionnaire:** https://doi.org/10.21954/ou.rd.22661593.v1; accessed on 25 March 2024. **Dataset:** https://doi.org/10.21954/ou.rd.c.6668648; accessed on 25 March 2024.

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Glossary

Abilities	These are innate or acquired capacities to perform tasks.
Skills	These are learned abilities or abilities gained through experience.
Competencies	These competencies encompass abilities, along with knowledge and behaviors to determine job performance.
STEM	Science, technology, engineering, and math.
Science	A systematic and organized approach to developing scientific knowledge through observation, experimentation, and analysis. It includes a wider range of disciplines, such as social sciences (e.g., sociology and geography), natural sciences (e.g., physics and chemistry), formal sciences (e.g., mathematics and logic), and applied sciences (e.g., engineering and medicine).
Open schooling	Education with Real-life problem-solving supported by schools, communities, and experts.

Appendix A. Questionnaire for Students

Table A1. Students' views about science in your life and world with CONNECT open-schooling activities.

(Constructs to analyze learning gains related to transversal skills)	1. What are your views about science in your life and world with CONNECT open-schooling activities
	2. Have you used any CONNECT activities on these themes: ( ) environment, ( ) health, ( ) energy, ( ) climate change, ( ) none, ( ) other
	3. Please describe what you produced at the end of the activity.
	1. HOW OFTEN DO YOU DO THESE ACTIVITIES OUTSIDE SCHOOL?
Practice	1.1. I do science activities outside school (e.g., neighborhood, park, and at home).
Research	1.2. I search for extra information related to science activities at home.
MultiLiteracies	1.3. I read about science at home (web, news, and books).
Dialogue	1.4. I talk about real-life problems to learn science.
Questioning	1.5. I ask interesting questions to learn science.
	2. WHAT ARE YOUR VIEWS ABOUT SCIENCE IN THE WORLD?
STEM appreciation	2.1. Science helps people around the world to lead pleasant, healthy lives.

Table A1. *Cont.*

STEM relevance	2.2. Science, technology, and math are important for solving problems.
Creative Thinking	2.3. Scientists need to use their imagination to solve problems.
Decision-making	2.4. Knowing science helps people to make decisions using information.
STEM Application	2.5. Learning science will be useful in my daily life.
	3. WHAT ARE YOUR VIEWS ABOUT SCIENCE IN YOUR FUTURE?
Career vision	3.1. Science knowledge and skills will help me to get a job.
Supportive interest	3.2. My family thinks science is interesting.
Valued incentive	3.3 My family thinks science will be important for my future.
Scientific literacy	3.4. My teachers have explained the importance of science in my life and society.
Encouragement	3.5. My teacher encourages me to keep learning science.
	4. HOW CONFIDENT ARE YOU WITH SCIENCE?
Cooperation	4.1. I feel confident doing science projects with other people.
Communication	4.2. I feel confident talking about science.
Scientific inquiry	4.3. I feel confident using science to come up with questions and ideas.
Reasoning	4.4. I feel confident using math to solve problems in science.
Knowledge	4.5. I feel confident with my knowledge in science.
Critical thinking	4.6. I know how to justify my views using arguments and evidence (facts or data).
	5. HOW DO YOU LEARN SCIENCE?
Meaningful discussion	5.1. Discussions with my teacher and students help me understand science.
Collaborative learning	5.2. Students should have opportunities to learn science with others (scientists, families, etc.).
Career networking	5.3. I know some people working with science to talk about what their jobs are like.
	6. HOW DO YOU FEEL ABOUT SCIENCE?
Enjoyment	6.1. Learning science is enjoyable for me.
Enthusiasm	6.2. Science activities are fun.
Confidence	6.3. Learning science is easy.
Global citizenship	6.4. I would like to do projects with others using science to improve the world.
Expertise	6.5. I would like to be seen as an expert in science.
Career aspiration	6.6. I would like a job that uses science.

Appendix B. Template of open-schooling practices for teachers

Table A2. Teaching Template to Report Open-Schooling Practice.

Demographics	• CONNECT—open-schooling coach: • Country: • School: • Teacher(s)'s name(s): • Year of birth: • Gender (optional): • Discipline(s) (Science, Physics, Chemistry, Biology, etc.): • Number of lessons utilized in open schooling: • Title of open-schooling resource utilized: • Type of science actions (structured or open scenario): • Curriculum topics covered:
About the Teachers' Students	• Grade: • Average age: • Total number of student participants: • Total number of students who completed science actions: • Was the CONNECT questionnaire offered to your students on a voluntary basis?

Table A2. *Cont.*

Participants Involved:	• Family Members • STEM Professionals • Field of Expertise:
CARE	• What real-life problem did the students investigate using the open-schooling approach? • Can you describe their involvement in the lessons related to the topic? • Which issues were they particularly concerned about or interested in?
KNOW	• What curriculum knowledge did the students apply to propose solutions? • Could you specify any new curriculum knowledge that was introduced? • What were the students' learning objectives and the outcomes achieved?
DO	• Can you detail what the students created or achieved by the end of their activities? • Which skills were honed during these activities?
Findings related to the open-schooling approach	• What challenges did you face while implementing open-schooling activities? • What strategies did you employ to overcome them? • Did community or family members take part in the activities? If so, in what manner? • Did scientists or STEM professionals participate in the activities? • If so, in what capacity and how was their participation beneficial?
Student Achievements:	• What were students' achievements in terms of knowledge, skills, attitudes, and values? • Are there any further comments or insights you would like to share?

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