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A SYSTEMATIC REVIEW OF RURAL SCIENCE EDUCATION: KEY IDEAS FOR DESIGNING TEACHING AND LEARNING SEQUENCES

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Abstract

In this article we present a systematic review and a brief bibliometric analysis to situate the international research on Rural Science Education in highly recognized databases. The purpose of this article is to propose fruitful approaches to design teaching and learning sequences in rural science education context, understood as a complex space where migration, economy, culture, climate change among other issues intersect. Results show that rural science education is not vastly explored, and that the empirical research is limited. Recommendations are bounded with other ways of knowing and the recognition of the local knowledges that are specific to the rural context, and key ideas for the design of Teaching and Learning sequences are proposed and exemplified to advance in this field.

Keywords – Rural science education, Systematic review, Teaching and learning sequences.

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1. Introduction

According to World Bank Data (2023a), 43% of the worldwide population is rural. When rurality is coupled with science education in the literature, we find discussions about science education quality as it relates to standardized testing, rural-urban comparisons, and the lack of relevant questions for contextual richness (Oliver, 2007; Oliver & Hodges, 2014; Panizzon, 2012). These discussions are constrained by supposed boundary conditions in the practice of research in science education (Moura, 2021) related to the concepts of effectiveness and evidence-based teaching, associated with positivistic research approaches.

Additionally, Buck, Chinn and Upadhyay (2023) point to the fact that there is more research based on urban than rural science education, and their analysis shows that rural science education has an approach based on the qualification of teachers and funding, and the supposed deficiencies identified. However, there is richness identified in the natural and cultural context (Tovio, 2017; Vera-Bachmann, Osses & Schiefelbein-Fuenzalida, 2012), and the relationship with Indigenous Knowledge Systems (Avery, 2013; Kassam, 2009; Zidny, Sjöström & Eilks, 2020). Beyond what research has revealed, the limitations in what is known about Rural Science Education (RSE) are concerning, considering that rural communities are going to be most impacted by ongoing climate change (IPCC, 2022). Therefore, there should be heightened interest in addressing the issues concerning such a large population worldwide. RSE has unique challenges, and by this we also proffer the idea that rural students are uniquely situated to be custodians of our environment in the future and will be important driving forces for our economies (Murphy, 2022).

This literature review synthesizes findings in the field of RSE, providing recommendations for enhancing classroom practices and for the effective integration of research to inform educational strategies within this context.

2. Background

Rural Science Education (RSE) is positioned as a complex and dynamic field of study. The discipline is defined by a deep intersection of local and global issues. These issues include rural-urban migration, economic stability, distinct cultural practices, and the direct impacts of climate change (World Bank, 2023a; IPCC, 2022). Although rural populations represent 43% of the worldwide population (World Bank, 2023a), international research specifically addressing RSE remains notably limited. Therefore, defining the progress achieved, systemic gaps, and practical limitations identified within this literature is critical.

Initially, the term 'rural' was interpreted traditionally as a territory or place with certain characteristics, such as population size, type of employment and distance to urban centers (Boix, Champollion & Duarte, 2015). However, contemporary perspectives in Human Geography challenge this static view of rural areas, defining 'rural space' as a relational construct (Rojas-Marchini, Rodriguez, Marchant & Troncoso, 2020; Murdoch, 2006). According to Massey (2005), space is shaped by interactions across scales, from global networks to intimate localities, allowing for multiplicity and heterogeneity. This perspective emphasizes that rural space is continuously constructed, changing and dynamic, not fixed or static. This perspective challenges the static portrayal of rurality found in traditional rural studies, which often neglect historical nuances and diverse perspectives, instead focusing on structural determinants and fixed identities (Rojas-Marchini et al., 2020). The complexity of rurality is often simplified by the pastoral image of the countryside, which fails to capture the abundant diversity found in rural settings (Oliver, 2007).

In international reports, different perspectives are situated to describe what is rural and non-rural. For example, in the 2018 Revision of World Urbanization Prospects (United Nations, 2019) states that 45% of world's population lives in rural areas. This report is focused on the urbanization process and alerts about persistent migration from rural to urban areas, where rural is just framed as non-urban. Another example is the 'Rural 3.0' framework proposed by OECD (2018) for rural policy. The description in this report considers diversity and the different needs and advances "from simple rural dichotomy to a continuous view of territories where rural is everywhere" (OECD, 2018: page 4). These different areas are: 1) Rural areas within a Functional Urban Area; 2) Rural areas with access to a Functional Urban Area; and 3) Remote rural areas. Even though this framework is a step forward, rurality is still defined by its relationship with urban centers.

Rurality and the 'rural' way of living are also changing because of migration trends. For one example, migration from rural areas to urban areas is constrained by economic precariousness and 'the lack of': this can be explained by supposed better economic opportunities in the cities, a more diverse and better educational and public services' offer, and also the early and immediate effects of climate change in the agricultural economy of rurality (Banco Interamericano del Desarrollo, 2021; Duncan & Popp, 2017). On the other hand, migrations from urban areas to rural areas, impulse by a healthier lifestyle, food sovereignty, gentrification, high living prices in urban areas and remote work since COVID-19 pandemic (The Guardian, 2020; Incaltarau, Kourtit & Pascariu, 2024; González-Leonardo, Rowe & Fresolone-Caparrós, 2022). These changes in the rural landscape might also affect the rural identity and the rural school, although the symbolic location of the rural school must be understood from perspectives that try to highlight rurality from its intrinsic value and unicity beyond the global maelstrom (Galván, 2020).

Rurality is a polysemic term based on the definitions proposed by different organizations. These definitions permeate policy as well as the understanding of rural places, and as such, research in RSE falls under the burden of such definitions that do not necessarily capture the richness and uniqueness of rural landscapes.

2.1. Thematic Progression and Gaps in RSE Research

Science teaching and learning processes are a diverse and complex field of study in science education. The goals of science education, according to Hodson (2010), focus on giving students a leading role, in Socio-Scientific Issues and problematize them, to encourage school students to be part of social and cultural changes through informed views. In this way, students get involved with and learn science, because it is relevant for their lives. Science teachers, more than mediators or facilitators in the classroom, are individuals that face restrictions from a system and curricula that has not yielded in considering a more robust vision about science learning, understanding science as important for student's present life and development.

Current discussions in the literature situate unique challenges for this pospandemic era. As an example, Souza and Oliveira (2024) caution against the pseudosciences and the lack of critical thinking, and how important is to advance science education practices that allow for accurate interpretation of scientific information and make arguments in the classroom to evaluate evidence and address biases. Marzábal and Merino (2024) state the multicausality of the challenges of science education in the Latin-American sub-continent: currently, students do not gain the scientific literacy needed to address contemporary social and environmental challenges. In Latin America, according to the World Bank Data (2023b), almost 20% of the population is categorized as rural, so it is appropriate to ask: What are the challenges for Rural Science Education?

The academic discussion on RSE has evolved over time. It has shifted its focus from identifying structural challenges, to proposing situated pedagogical models. Early literature primarily focused on quality discussions involving standardized testing and rural-urban comparisons (Oliver, 2007; Panizzon, 2012; Oliver & Hodges, 2014). To clearly illustrate this conceptual progression and its associated limitations, Table 1 summarizes the core contributions of the foundational frameworks in RSE research.

The tematic evolution shown in Table 1 reveals a shift in the field. Research moved from identifying structural barriers (Oliver, 2007) to strongly advocating for culturally responsive and situated pedagogy (Oliver & Hodges, 2014; Buck et al., 2023). However, despite the rich conceptual tools provided (e.g., Funds of Knowledge, Place-Based Education), a significant gap persists. Direct and detailed suggestions for teachers and curriculum developers on how to execute teaching and learning processes in the rural science classroom are not entirely clear. This lack of explicit instructional guidance is a recurring issue in the literature (Galfrascoli, 2013; Carrete-Marín, Domingo-Peñafiel & Simó-Gil, 2024). This gap underscores a persistent need: the articulation of the theoretical value of RSE with concrete, flexible teaching methodologies. This requirement justifies the use of the Teaching and Learning Sequences framework (Méheut & Psillos, 2004) to support rural science teachers regarding the skills and orientations for designing, organizing, and assessing their work with their students.

Author(s)	Main conceptual focus	Identified limitations/challenges
Oliver (2007)	Structure and relevance need: defining rurality by the lack of science and technology. The need for research to go beyond simple rural-urban comparisons.	Lack of consensus on rurality definition. Condition of isolation and the need for equitable technology access.
Panizzon (2012)	Methodological and systemic gap: analysis of academic performance and educational policy. The need for a new characterization of diverse rural ways of life.	Inconsistencies in results due to diverse rurality definitions. Insufficient consideration of key variables like ethnicity and socioeconomic status.
Oliver & Hodges (2014)	Situated Pedagogy and Sense of Place: Emphasis on Sense of Place and the strong school-community relationship. Promotion of Place-Based Education.	Need to advance research on questions relevant to the local context. Requirement to promote technology and achievement in STEM disciplines.
Buck et al. (2023)	Local conceptual tools: proposes four tools to prioritize the locale: Socioeconomic Status/Resources, Science Identities, Funds of Knowledge, and Place-Based Education.	Perceived displacement of RSE as a recognized field (merged with the Urban chapter). Structural challenges persist (e.g., professional development, achievement gaps).

Table 1. Conceptual progression and associated limitations in RSE research

2.2 Teaching and Learning Sequences

The research on Teaching and Learning Sequences (TLS) dates from the 1980s, as investigations of teaching and learning at a micro- and medium- level, not as a whole unit of long-term curricula (Méheut & Psillos, 2004). A TLS is understood as organized and systematic activities that approach and solve a school science curricular issue (Izquierdo-Aymerich & Adúriz-Bravo, 2003). TLS are a way to plan and design both processes of teaching and learning, and this approach considers which content, context, and objectives are taught, and in what order, also in what way this is implemented, and how the teaching and learning activities are assessed (Méheut & Psillos, 2004). This broad definition of TLS then, includes all artifacts used in the classroom by teachers, as materials and resources (e.g. games, analogies, videos, simulations, laboratory, stories, models, etc.) and poses TLS as a tool for science educators that articulates the meaning of the process -why and for what purpose we teach science- with the concrete work in the classroom -what is taught and how it is taught- (Couso, 2011).

According to research in TLS (Méheut & Psillos, 2004), activities and products have a dual character: drawing from the tradition of action research, they involve research and development while addressing the teaching and learning of a particular topic. TLS are a versatile approach because they are "both an interventional research activity and a product, like a traditional curriculum unit package, which includes well-researched teaching–learning activities empirically adapted to student reasoning" (Meheut & Psillos, 2004: page 516), and their research process combines the scientific and student perspective (Meheut & Psillos, 2004).

To pose an example about TLS and their design, we are drawing upon the work of Muñoz-Campos, Franco-Mariscal and Blanco-López (2020). Their TLS design framework consists of three stages: i) formulation of the design principles to prepare the design, as pragmatic aspects of practice as well as the learning theories informing the TLS; ii) instructional design "to identify and sequence the tasks in the TLS" (Muñoz-Campos et al., 2020: page 10), and considers choosing the context, proposal of questions, drafting objectives, selection of knowledge, and the design of the learning activities and evaluation; and iii) design of the learning activities, combining the design principles and instructional design, considering number of class sessions, the characteristics of the group that is participating in the TLS and the available resources.

This article aims to explore the emergent field of RSE, questioning also in this stance if RSE should have a distinct lens to approach the design of TLS. There is criticism, for example from Galfrascoli (2013), regarding that RSE is promoted from an urban standpoint, considering that we replicate national standards, grades and sometimes lessons in rural classrooms. Due to the latter, this research aims to give proper orientation, through revising available research, for designing TLS for RSE, also considering that the tradition in TLS design requires evidence that supports expansion (Méheut & Psillos, 2004). Following this logic, we also aim to unpack where the research is coming from, and who's research is more influential in RSE.

3. Methodology

A systematic review of the literature using the PRISMA protocol (Page, McKenzie, Bossuyt, Boutron, Hoffmann, Mulrow et al., 2021) was conducted to answer questions regarding the framework for designing TLS for RSE. A systematic review, instead of a scoping review, takes into consideration: international evidence, influential countries and researchers, trends in teaching praxis, key research areas, and public policy, among others.

Our systematic review was conducted in three phases, in Phase 1 we formulate a research question aligned with the purposes of 1) analyzing tendencies in research about school RSE, and 2) assess class design and/or planning in research in school RSE. In Phase 2, already with a whole dataset of literature, a bibliometric analysis was conducted to disclose the relationships that might occur between different research gathered. For bibliometrics, the Bibliometrix R Package (Aria & Cuccurullo, 2017) was used to measure the cited literature, as well as international collaborations. Finally, in Phase 3, we analyzed the relevant literature in the light of the research question, emphasizing the class design and/or planning, and synthesize the main findings.

3.1. Phase 1 – Planning the Review

3.1.1. Research Question

The aim of this research was to identify trends in publications related to the field of school RSE. We analyzed the contributions made by scholars, specifically the development and implementation of curricula in the classroom, to gain knowledge about research in this area and use findings to build up criteria to design a TLS. Regarding this, the main question that guides this review is: How are lesson plans characterized and implemented in RSE research?

3.1.2. Review Protocol

Before doing the literature search, we developed a review protocol to strategically locate the literature about the research theme. Given a previous attempt as a scope review in the field of RSE (Iturbe-Sarunic & Merino, 2021), we recognized that there is not extensive research on this topic, and that some documents found do not have high quality standards. Thus, this review was conducted in two high-quality databases - Web of Science and Scopus. Both databases deliver a richer set of metadata (references, countries, etc.) to be analyzed with a bibliometric strategy. The review protocol is detailed in Table 2.

Databases	Web of Science, Scopus
Document type	Published journal articles
Search fields	Title, abstract, keywords
Publication dates	1968-2024

Table 2. Literature review protocol

As this review aims to illuminate how school RSE is represented in literature, we used Boolean strings related to this concept, collecting articles that fit the criteria of our literature review protocol. After exploring different research in databases, search terms were decided as ("rural science education" AND school) OR (rural AND "science education" AND school). A discrete bibliometric analysis was conducted after retrieval of sources from databases, to address trends and tendencies in research worldwide.

After retrieving the articles and bibliometric analysis, inclusion and exclusion criteria for final articles to be fully reviewed by the authors were defined, to address properly to the research question, detailed in Table 3. The selection of only peer reviewed journal articles aimed to include research that responded to high standards, regarding the experience in the previous scope review. As this research looks for RSE in schools, the context is well delimited, and choosing only empirical research intends to gather evidence assessed by others (peer reviewers), to construct the corpus of data for this study. The subsequent criteria, regarding the description of the activities and the focus in rurality, address the frameworks and research previously discussed regarding challenges in RSE and the design of TLS.

Inclusion	Exclusion
Publication type: peer reviewed, journal articles	Conference papers, book chapters, reports
Context of the study: school science (students, teachers, community)	University programs (e.g.: teacher training, scientific training, engineering training)
Methods: empirical research	Essays, reflections, letters to editor, literature reviews
Activities: explicit description, sequencing, goals, assessment	Activities not fully described
Rurality is in the center and is relevant for the research	Rurality is fortuitous for the research

Table 3. Inclusion and exclusion criteria of the review

3.2. Phase 2 – Conducting the Review

3.2.1. Identification of Relevant Research

The search in the databases indicated in Table 2 was conducted on January 17th, 2024. The metadata was extracted from each database and uploaded to R according to the methods described by Aria and Cucurrullo (2017). This procedure in R eliminates duplicates, obtaining a total of 188 documents to start with as shown in Table 4.

Database	Documents retrieved
Scopus	153
Web of science	109
Final count without duplicates	188

Table 4. Number of results returned from database searches and total documents

Using this tool, we wanted to know before reading the content of the relevant research, different trends in the data. Using R software and the WriteXLS package, 188 articles were obtained and screened. Using Biblioshiny (Aria & Cucurrullo, 2017), the main information about these articles is shown in Figure 1.

One of the considerations that must be raised is the 56 years timespan of the field of RSE. Also of note is there are around 3% of international co-authorship in this field of study. Information regarding most relevant affiliations and authors is available in Supplementary Information. According to the analysis Biblioshiny does to metadata, the most productive country in RSE is the United States of America (USA); in second place is Australia and third is South Africa. It is important to highlight that there is a wide range of countries from different continents represented in this dataset; this information is also available in Suplemmentary Information.

Figure 1. Main data obtained from Biblioshiny on January 17th, 2024

Finally, we sought to identify the most frequently cited studies among the 188 screened articles to better understand the key influences on RSE research. Probyn (2015) and Amaral, Garrison and Klentschy (2002) were first and second most cited; both articles address issues related to languages and science instruction in rural schools. Avery (2013) is the third most cited and poses a framework to address RSE in the classroom. Other research related to other ways of knowing and approaching science education in the rural context are relevant, as well as methodological aspects that categorize the research as qualitative in nature, that are specified in Supplementary Information.

3.2.2. Selection of Primary Studies

The 188 articles were then screened to remove those that did not comply with the inclusion criteria regarding the context of the study and methods (Table 3). All abstracts were read to exclude the research that addressed higher education (University, teacher training, scientific training) and not empirical research. This process removed 81 articles, leaving 107 for further reading. For the remaining articles, they were classified according to the object of the study. From this, five different fields were recognized: school (57), teachers (34), knowledges (3), and public policy (13); they are shown in Supplementary Information. As the main challenge of this review is to gather research about science classes in rural schools to pose suggestions to design TLS, only the 57 articles addressing RSE in a school level were further analyzed.

3.3. Phase 3 – Extraction and Data Synthesis

In this phase, the 57 articles that addressed RSE in a school level were fully read. At this stage, the inclusion criteria regarding the description of the activities are most important, to answer the research question that guides this review and thus proceed to more in-depth analysis: How are lesson plans characterized and implemented in RSE research? The process to reach to the final 15 articles is synthetized in Figure 2.

4. Results and discussion

4.1. How are Lesson Plans Characterized and Implemented in RSE Research?

From the 57 articles screened for an in-depth review about approaches that contribute to designing new TLS for RSE, the analysis further separated the relevant research found in previous stages and gave a sense of the different educational approaches that are being implemented in RSE research. Through the analysis, 15 relevant research articles were finally considered, because they described not only their framework, purpose and topic, but also rurality. The route to reach these 15 articles is shown in Figure 2, articles' details are in Table 5.

Despite being a small number of articles, the countries in which the research is carried out represent all continents. The variety of journals accounts for diversity in publication venues. This, which from the authors' perspective, helps construct key ideas based on multiple sources to address gaps in literature. Although the timespan is broad, most of the research has been conducted within the past seven years.

From the reading and reflection of the aforementioned research, it is possible to identify that scientific inquiry as a strategy or methodology of teaching and learning is implemented and researched in different rural school classrooms. Place-based education is also very important; Funds of Knowledge and community participation also stand out. With this, we then highlight two topics that group different articles, such as *Inquiry and Hands-on Approaches* and *Community and Culturally-sensitive Approaches.*

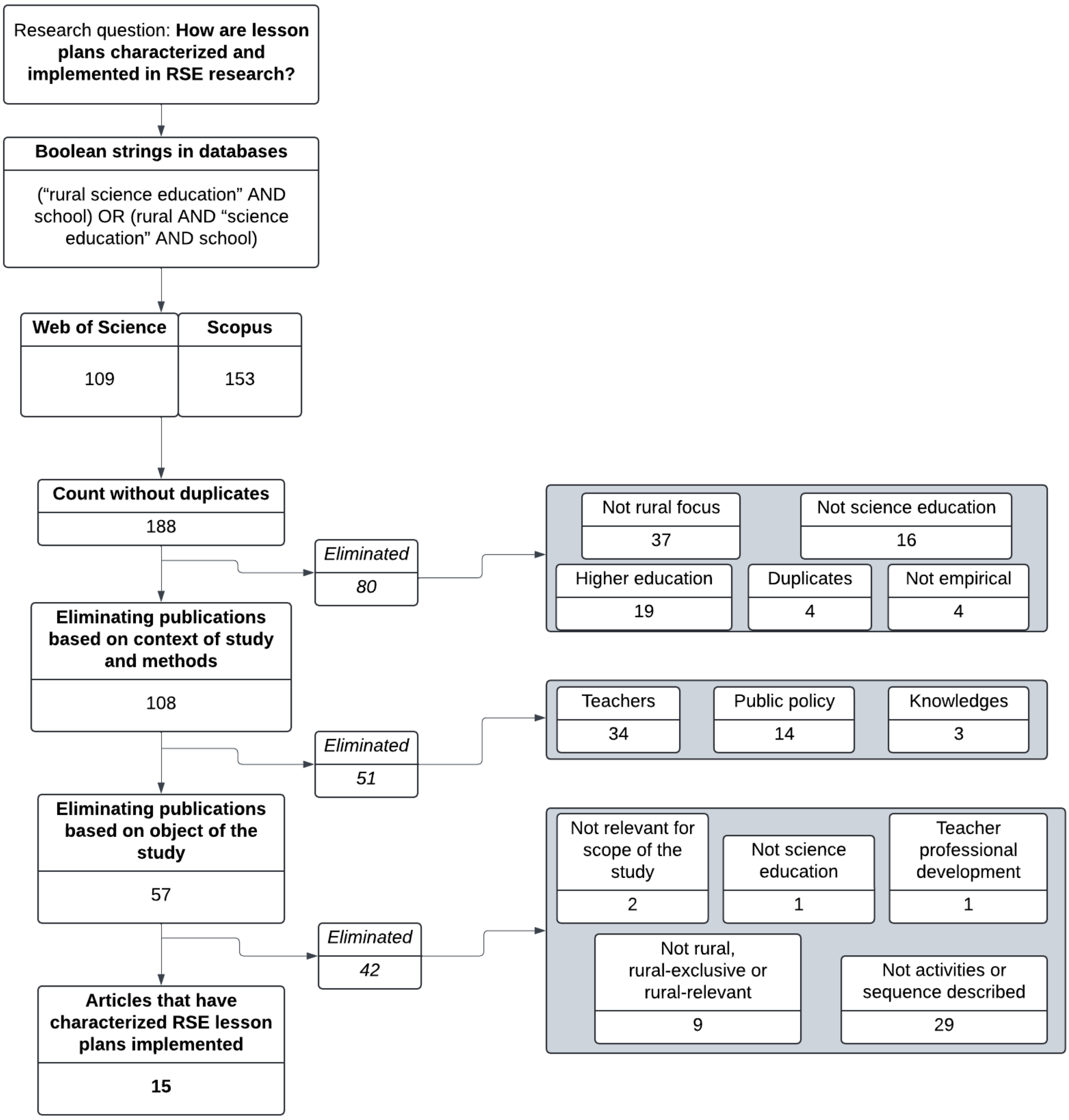

Figure 2. Review based on the PRISMA protocol (Page et al., 2021)

4.2. Inquiry and Hands-on Approaches

The systematic review reveals that most empirical studies in RSE primarily use inquiry and hands-on approaches. Key findings indicate that these methods effectively increase student motivation and performance. However, a crucial limitation is observed: the design of these sequences or lesson plans often focuses on replicating standard scientific research models and employs generic content, failing to achieve a deep connection with the specific social, economic and cultural context of rural communities. This gap highlights a disconnection between pedagogical practice and the need of training rural citizens using local knowledge.

Scientific inquiry has permeated school culture around the world and in various contexts according to different approaches, it promotes scientific inquiry from a student-centred perspective, the improvement of attitudes towards scientific activity, the promotion of the use of instruments, the development of scientific skills, data collection, the generation of conclusions and the communication of these results (Bybee, 2011).

Reference	Title	Journal	Country
Borgerding (2017)	High school biology evolution learning experiences in a rural context: a case of and for cultural border crossing	Cultural Studies in Science Education	U.S.A.
Coltogirone, Kuhn, Freeland & Bergeron (2023)	Fish in a dish using Zebrafish in authentic science research experiences for underrepresented high school students from West Virginia	Zebrafish	U.S.A.
Conceiçao, Baptista & Reis (2019)	Hydric resources pollution as a trigger for socioscientific activism	Eureka	Portugal
Cruz, Selby & Durham (2018)	Place-based education for environmental behavior a funds of knowledge and social capital approach	Environmental Education Research	Costa Rica
Havu-Nuutinen, Kärkkäinen & Keinonen (2011)	Primary school pupils perceptions of water in the context of STS study approach	International Journal of Environmental & Science Education	Finland
Hetherington, Eggers, Wamoyi, Hatfield, Manyama, Kutz et al. (2017)	Participatory science and innovation for improved sanitation and hygiene process and outcome evaluation of project shine a school-based intervention in rural Tanzania	BMC Public Health	Tanzania
de-Melo, Martins-Batista & de-Souza-Camargo (2021)	Rural education and science teaching experiences in a riverside school in the southwest amazonas	Revista Brazilera do Eduacion do Campo	Brazil
Morales, Acosta-García & Rodríguez (2022)	Teachers' role and scientific inquiry analysis of an experience about pests in a Chilean rural school	Eureka	Chile
Morris, Slater, Fitzgerald, Lummis & van-Etten (2021)	Using local rural knowledge to enhance stem learning for gifted and talented students in Australia	Research in Science Education	Australia
Pineda-Caro, Valderrama & Torres-Merchán (2023)	Didactic intervention for the teaching of stellar astrometry in field educational contexts	Acta Scientiae	Colombia
Puslednik & Brennan (2020)	An Australian based authentic science research programme transforms the 21st century learning of rural high school students	Australian Journal of Education	Australia
Rao, Shamah & Royce (2003)	Involving graduates and undergraduates in science education in rural Oregon schools	American Enthomologist	U.S.A.
Santamaría-Cárdaba (2020)	Families experiments and nature learning science through project-based learning	School Science and Mathematics	España
Silveira-da-Rosa, Moreira-Rodrigues & Lima-Robaina (2021)	Pedagogical chicken a space for scientific literacy in the science club	Revista Brazilera do Educacion do Campo	Brazil
Zimmerman & Weible (2017)	Learning in and about rural places connections and tensions between students' everyday experiences and environmental quality issues in their community	Cultural Studies in Science Education	U.S.A.

Table 5. Relevant literature for this review

From the articles analyzed, different ways of promoting inquiry are observed; however initiatives outside the classroom clearly stand out, such as science camps (Coltogirone et al., 2023), science academies (Morales et al., 2022) and proposals in which students are directly supported by teams of researchers to achieve their inquiries (Puslednik & Brennan, 2020; Rao et al., 2003: Morris et al., 2021). There is a prominence of extracurricular activities or after school activities, serving a specific or interested population. However, these training spaces do not cater to the entire school population, but to students who fit into a category of 'gifted', 'talented' or 'interested'. Despite this, the purposes that unite the aforementioned research are related to the access that rural students have to learning opportunities in the fields of science and experiences that allow them to expand their field of action, improve conceptual and procedural learning, increase their confidence and open the opportunity to higher studies, establishing links with people who are dedicated to scientific research in universities.

On the other hand, initiatives that combine inquiry with context can be seen in Conçeiçao et al. (2019), Havu-Nuutinen et al. (2011), Zimmerman & Weible (2017) and also in Morris et al. (2021). In Havu-Nuutinen et al. (2011) we observed a framework related to STS (Science-Technology-Society) approach, and the purpose of the teaching is to promote more systemic visions of water resources, through thematic units that address from conceptual issues (e.g. water cycle), to water problems (e.g. floods, droughts); there is an interesting analysis students' representations and reflections, emphasizing different instruments to account for their learning. In the case of Conceiçao et al. (2019) there is a strong component related to student activism, in relation to a socio-scientific issue (SSI) such as the contamination of a watershed. The design framework of the activities is based on Bybee's 5E (Bybee, 1997 in Conceiçao et al., 2019) and the activities aim at both student understanding and action, which is consistent with the proposed activist approach (Reis, 2014). In Conceiçao et al. research, activism is reflected in activities outside the classroom, where the development of a radio club stands out for the engagement it produces in students and in their action as members of a community also stressed by the political problems that this SSI involves.

Activities presented in the thematic unit of Zimmerman and Weible (2017) are part of a structured inquiry, which aimed to answer questions about the health of a water stream site and the evidence that should be collected to prove it. The following section discusses the community-related components of the research.

Despite researching a select group of students (talented and academic extension programme), Morris et al. (2021) draws from Avery's Local Rural Knowledge (2013) the possibility of collaborative and interdisciplinary work (indigenous community, scientists, teachers) for the restoration of degraded soils with plants. In this research, it is intended to integrate the Local Rural Knowledge -LRK- (Avery, 2013) with the Australian curriculum and standards, putting the student at the center of the teaching and learning process, achieving through this project powerful results that demonstrate the learning and engagement with science.

It is important to note that among the analyzed proposals, other scientific practices (Bybee, 2011) such as modelling or argumentation, are not present within the research. This indicates that there is a field of action that can be explored for RSE and all the opportunities that this might bring.

This group of articles put a light on various initiatives which are valuable contributions to the field of rural science education, integrating hands-on and inquiry approaches (Rönnebeck, Bernholt & Ropohl, 2016). The theme that has emerged in these groups are the equitable opportunities for all rural students in the field of science, and as stated by Eppley (2017), 'Rural Science Education as Social Justice'. By this we stand for overcoming those educational obstacles and advance in providing these engaging educational experiences, because rural students and their communities need to "balance the scales of justice in rural places" (Eppley, 2017: page 51). The path forward is to systematically incorporate these hands-on and inquiry approaches to the 'regular' science classroom.

4.3. Community and Culturally-sensitive Approaches

In contrast to approaches based solely on inquiry, a significant minority of the literature actively promotes the integration of local and culturally-sensitive knowledge within RSE. The results from this research demonstrate that recognizing and utilizing community knowledge (e.g., agricultural practices, water resource management) not only validate the students' environment but also enhances the understanding of scientific concepts in a relevant manner. This approach is presented also as a methodological proposal with greater impact and relevance for addressing complex issues such as migration and climate change, thereby overcoming the limitations that may characterize purely inquiry-based approaches.

The partnership between school and community is fundamental for renewal and progress in the rural educational context, in matters such as social capital, sense of place, parents' involvement, among others (Bauch, 2001). This alliance is of great relevance in giving meaning to learning within the school context in order to relate it to the practices that are established within the rural community, since the rural school context has an impact on the construction of meaningful learning for students (Díaz, Osses & Muñoz, 2016), with close and particular relationships with the natural environment and among the people who inhabit it. Students in these territories have repertoires of knowledge and experiences related to nature. This projects situated, relevant, and pertinent learning opportunities (Tovio, 2017; Vera-Bachmann et al., 2012). This section highlights approaches that integrate traditional knowledge and community knowledge, because of the dialogue they generate with the scientific knowledge found in standards, textbooks and curricula.

Within the articles, there are research that incorporates traditional knowledge such as Silveira-da-Rosa et al. (2021), with the *Galinheiro Pedagógico* (pedagogical henhouse), with which the knowledge that students already have is worked on, from an Ausubelian approach focused on meaningful learning, with a strong emphasis on valuing the local knowledge of the community in which it is inserted. In this research is not highlighted but parents also help articulate the actions regarding construction and support of this initiative. de-Melo et al. (2021) integrates the traditional knowledge of students from a community in the Amazon-Brazil, where students' knowledge is valued and rescued for the teaching of plants and ecology. Their social, cultural and environmental knowledge dialogues with scientific knowledge and accounts for a close relationship between humans and plant species in this space.

Regarding inclusion of the community in the research, the SHINE project (Hetherington et al., 2017), carried out in Tanzania articulates not only the school but also integrates the community in the development of an innovation to improve practices associated with water hygiene and sanitation. The development of workshops and thematic units that involve school and community learning, the socialization of different measures to promote collective improvement and the monitoring and commitment of a community around innovation and well-being account for the relevance of alliances with community actors so that school scientific knowledge goes beyond the walls of the school.

Borgerding (2017) addresses the border-crossing between the culture of the religious rural population and the acceptance of evolution as a school scientific model, through the characterization of the teaching processes carried out by the biology teacher. Funds of Knowledge (FoK) (Moll, Amanti, Neff & Gonzalez, 1992; González, Moll & Amanti, 2005) is taken into account as a starting point for the instruction. FoK structures the way students might accept or not the new ideas of scientific culture, understood as a system of knowledge and practices perhaps alien to them, where the teacher is the one who makes this 'tour guide' towards the dialogue between both positions and knowledge.

The framing of the FoK as an articulator of the dialogue between knowledges is also addressed by Cruz et al. (2018). This research is carried out with a strong community component, developing a curriculum that integrates knowledge of place, gathered through interviews with local students, community partners, educators, business owners, entrepeneurs and self-selected community leaders. FoK drawn from these interviews are shown in their research as a starting point to their environmental education programme, where not only students and researchers participate, but also members of the community teach based on their knowledge and practices in this specific context. The curriculum is certainly identified as Place-Based (Gruenewald, 2003), as are other research.

Zimmerman and Weible (2017) also develop thematic units in relation to water, with rural students under a Place-Based lens, identifying the tensions between the identified problems of water quality, and the lack of possibility of action by young people; in this sense, they highlight the need to incorporate components of collective action in environmental education and students as community agents of change progressively in the curricula. This also advances in including rural students and communities in the participation needed regarding socioenvironmental issues in rural places, as an action for social justice (Eppley, 2017).

Santamaría-Cárdaba (2020) conducts science classes framed in Project-Based Learning (PBL), incorporating the family and field trips in the natural space. The contents based on national standards (Spain) are related to plants. Classic experimental activities were carried out, in addition to field trips where family members participated as spokespersons for local knowledge about plants, which also strengthens the school-community link according to this research. Integrating culture and knowledge from communities and place to curricula, represented, a partnership needed to implement the Place-based educational approach in the classroom initiatives.

Despite the fact that there is no specific didactic approach mentioned, the research by Pineda-Caro et al. (2023) reports on an intervention carried out to offer new knowledge to rural students, although based on specific scientific knowledge (stellar astrometry), specifically on methods and techniques to also promote the recognition of technological advances in the area. However, according to the authors, this article does not enter in any of the two thematic groups, because it pursues objectives rather related to a technical scientific literacy or vision I according to Sjöström and Eilks (2018).

In summary, in addition to identifying the theoretical frameworks with which the research reviewed in detail is grouped by themes, it is also possible to indicate thematic areas and phenomena addressed, mainly water and ecology, and an example of astronomy and health sciences. Likewise, in the context of instruction, it is relevant to note that several investigations are not located in science class, but in workshops, camps, and science clubs. The above is represented in Figure 3 and all relevant research (15 articles) instructional contexts, topic and frameworks are detailed in Suplemmentary Information.

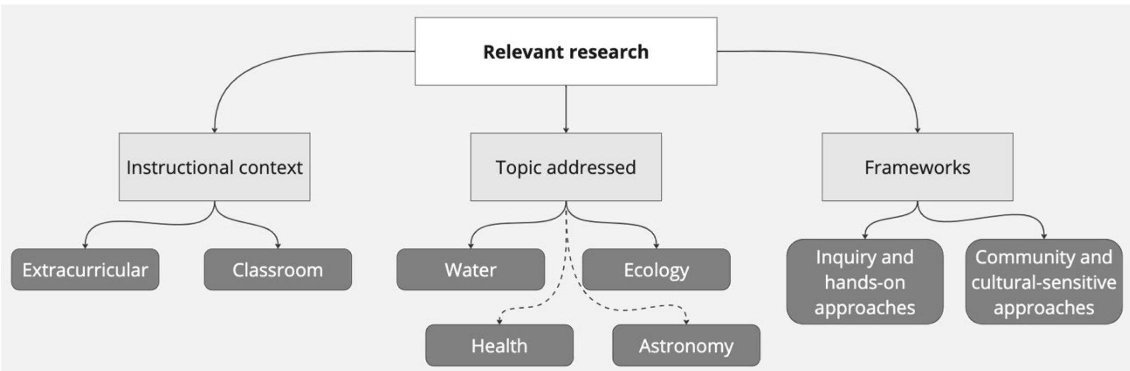

Figure 3. Synthesis of themes in relevant research revised

4.4. Key ideas for designing TLS

This systematic review of the literature aimed to provide information based on relevant research for designing TLS in RSE; this guidance can be considered by teachers, educational administrators, policy makers and organizations that are strongly involved with rural communities. The guidance here proposed is structured in Key Ideas that are not closed, rather open-ended, to continue the discussion about RSE in further research. Accordingly, we pose questions at the end of each Key Idea to guide the TLS design process.

4.4.1. Key Idea 1: Educational Goals for All RSE Students

Among the different literature revised, there are various educational aims stated. In this sense, approaches are found, that are an effort for some students to pursue higher education -learn science or STEM content to achieve higher education-, and others that are focused in solving local issues in collaboration with the community. Rural schools are schools, but they are situated in a rural space that and encompasses diverse relationships (Massey, 2005; Rojas-Marchini et al., 2020; Murdoch, 2006). According to as stated at the beginning of this article, rurality is not static, rather dynamic and the challenges for RSE are specific to the environment, natural 'resources', other ways of living (Murphy, 2022; Panizzon, 2012; Oliver & Hodges, 2014)-, and also global in the field of science education -that what is learnt is meaningful for the present time and the future and that what we learn can helps us understand, improve and/or transform our reality (Marzábal & Merino, 2024; Hodson, 2010). This understanding should be carried over into the lessons that are taught and learned in school, and hopefully with all students.

Through the analysis, we stated that all projects and research that was with the community and/or related to traditional knowledge, included all students. On the contrary, much research that had higher educational aims, segregated more and worked with 'special' groups. To start this discussion, drawing from the research here revised, we propose these questions: What are the needs of the rural students, their community and place? How to meet national/regional/state standards in dialogue with inclusion of all students in meaningful science lessons and experiences? Do teachers have a community that support them? Is there a relationship built between school and community?

4.4.2. Key Idea 2: Topics Addressed in Class

In the classroom interventions found in the literature, we state that the content addressed is mostly related to Biology: Ecology, Environment, Biodiversity, Evolution, among others; water issues are also a topic addressed that talks much about are the problems that rural communities are living. Then, there is a debt in RSE classroom addressing the variety of scientific disciplines, so meaningful learning experiences are provided to students that engage more profoundly in the phenomena that is being analyzed, enriching their understanding and dialogue of knowledge (Leff, 2001).

When learning experiences have a focus in providing culturally relevant experiences, students can cross those cultural borders and have equitable learning experiences (Miller & Roehrig, 2018). Dialogue of knowledge (Leff, 2001) is an opportunity of place-relevant knowledge helps to stand out the ethical, political and cultural nature of issues in the rural space and gives the space to build experiences around real problems of the cultural context (Mora-Penagos, 2019). In school contexts so closely linked to nature such as rural schools (Tovio, 2017; Vera-Bachmann et al., 2012), there are possibilities to promote a re-signification of human-nature relations through experiences that consider the culture, practices and knowledge of its inhabitants.

The instructional design also must be aligned with this lens: just providing the experiences won't be enough. Activities aligned with valuing local knowledge and culture such as participation of people from 'outside-the-classroom' -local leaders, elders, families, business owners, among others- will make a difference. However, students need to have also adequate instruments such as logbooks, field diaries, audiovisual records, photography, drawings, among others, that allow them to capture the different concepts and experiences, allowing them to later reflect on and discuss the scientific topics in class as well.

Questions raised for this key idea: What are the students' interests or concerns? Which scientific disciplines are related to the issue/content/local knowledge that is going to be addressed in class? Are there other knowledges (community-based, indigenous, traditional) related to what is going to be taught in science class? What kind of instruments and activities can challenge rural students to engage with scientific content?

4.4.3. Key Idea 3: Knowledge-in-Action (KiA) as a Culturally Responsive Framework for RSE

Some of the classroom research and other themes that emerged from the review showed that there are frameworks that value other ways of knowing for learning science in the rural classroom. They highlight the relevance of the rural space in the process of teaching and learning science: PBEd, Funds of Knowledge, Traditional Knowledges, SSI, Inquiry and scientific practises; we propose to call the intersection of these perspectives with a RSE lens as Knowledge in Action (KiA, Figure 4). KiA emphasizes the relationships between scientific knowledge, people's knowledge and the phenomena found in the natural rural space. This recommendation for designing TLS in RSE, we state that is a design principle (Muñoz-Campos et al., 2020) and aims to move forward with educational initiatives that involve the community, relate scientific knowledge and practices to real phenomena and issues, respecting the diversity of world views and ways of living in the rural space. As is stated in Arboleda Piedrahita, Gómez Galindo and García Franco (2024), Place Based Education in science education that addresses meanings and sense of place is a path for a meaningful science education for all, serving as "epistemic justice" for places where local phenomena can be addressed in the classroom taking into account local knowledge and scientific knowledge.

Questions that continue the reflection in the KiA path are: What do students/teachers/parents/community leaders know about the concepts that are going to be addressed in science class? What local phenomena or practices are related to these concepts? Are there local problems or issues associated with these concepts? How the learning of these concepts can be intersected with local practices or knowledges? Can students gather local data to analyze a problem or issue related to these concepts? Can learning these concepts support community involvement in the teaching and learning process?

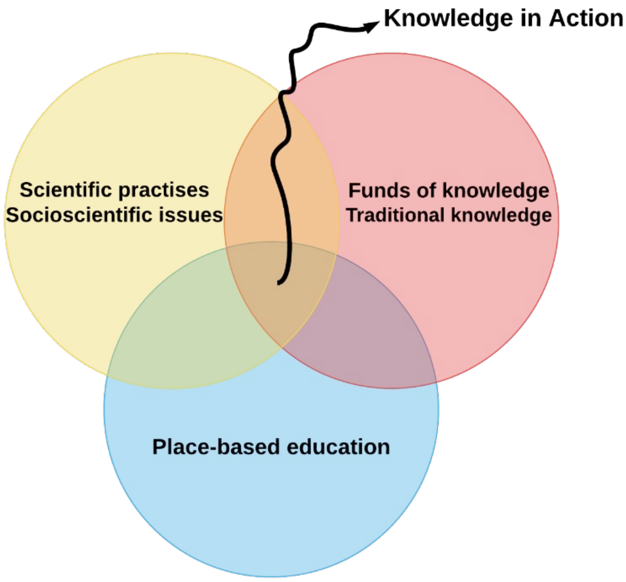

Figure 4. KiA diagram as an intersection of frameworks

4.5. An Example to Address TLS with RSE Key Ideas

In the following lines, a TLS initial design using the RSE Key Ideas will be shown, using a specific case: a rural community in the Chilean Northern Patagonia and the purpose of designing a science TLS to address the water cycle in that context. This description was part of a PhD dissertation about RSE.

4.5.1. RSE Key Idea 1. All Students (and their Families)

- The community sustains itself through fishing, tourism, livestock, and agriculture. There is a need to preserve the natural habitat that sustains all these activities and the natural surroundings.

- Some of the people are part of an indigenous community.
- The community administrates their own water supply.
- There is a strong community that is organized; the community supports schools and teachers; teachers are part of the community.
- Students must meet science standards (learning objectives) from the national Ministry of Education. Science standards are the same for all students in the country (Chile).

4.5.2. RSE Key Idea 2. Topics to be Addressed

- Students are concerned about sea water pollution (it is a fiord), water quality from streams, rivers, and hot springs, and floods caused by rising rivers. They are interested in preserving wildlife and the natural surroundings.
- Multiple fields of science are related to the issues before stated: chemistry, ecology, geology, for example.
- Students could show their learning gains through activities where they collect and analyze water data of their interest in their rural surroundings, working with members of the community and communicating their results to different communal organizations.
- Instruments that could help to engage with this scientific experience in context could be a logbook, to document their findings; also, worksheets that guide the data collection and help understand the variables that are being involved in their analysis. Finally, any kind of product elaborated by them that communicate their findings to their community might help also to connect the local knowledge and promote action outside the school.

4.5.3. RSE Key Idea 3. Knowledge in action

- People from this community are related to different kind of waters to be used for diverse reasons: seawater for fishery, groundwater and rivers for consumption and irrigation, hot springs water for tourism.
- According to some indigenous people from this community, there are ceremonial and medicinal uses to different waters that come from the mountains, for example.
- Humans have changed the course of rivers and that has affected their quality of life: floods occur more often and sometimes drinking water has debris, that makes water supply difficult.
- Because of complexities in water supply (water cut-off), classes can be suspended in school. There is also water scarcity in the summer, during the tourism season.
- Students could work with local data to get a grasp about their local rural water quality, and elevate them not as spectators or consumers, rather that doers and decision-makers.
- Learning, doing, and reflecting in the science class about water quality, can involve the community directly because the space where they live has an own water station that is administrated by the community, and students could advise through their research to their local water administrator.

5. Conclusions and Final Remarks

The aim of this review was to present orientations for designing TLS tailored for RSE. This objective was successfully met by synthesizing empirical evidence and foundational frameworks. The review established that designing an effective TLS for a rural school must first draw upon LRK. This knowledge serves as a highly valued framework for connecting the community's Funds of Knowledge with the student's Sense of Place. This conception of Sense of Place is central. It confirms that not only the natural environment is involved, but also the community and culture, acting as an ecosystem that interacts with the school and significantly promotes students engagement with the science class.

Considering these findings on LRK and PBEd are fundamental to adapting the instructional design to the student thinking, we posed three Key Ideas for designing RSE-focused TLS:

1. First, working in a rural setting requires a specific understanding of the rural space as dynamic. Therefore, educational goals must be directly intersected with the needs that the local and school community explicitly require to meet.
2. Second, the diversity of scientific fields offered in the learning experiences should be miscellaneous and context-relevant. The assessment of learning must integrate the richness of the rural environment and classroom. This approach also views combined classes in rural schools (multigrade) not as a difficulty, but a direct opportunity for learning science.
3. Third, we propose the Knowledge-in-Action (KiA) approach. This framework combines different theoretical perspectives to enhance the value of rural spaces and the knowledges accumulated by their inhabitants, specifically valuing different ways of knowing in dialogue with the scientific content taught in class.

These articulated recommendations provide a comprehensive perspective on the necessary next steps for contributing to the RSE research field. They specifically guide the design of TLSs existing knowledge about this educational context. Future challenges in this field of study involve empirically assessing the integration of the Key Ideas posed here as design principles. Further work is needed to advance in instructional design and specific activities within the TLS framework. Another critical challenge is promoting international collaboration, as the literature reviewed demonstrates that educational initiatives across various countries are framed under similar perspectives.

Although this review did not focus on systemic issues, existing research confirms that RSE faces diverse challenges regarding administration, technology inclusion, teacher professional development, and public policy. Ultimately, this article is also a call for more research in the RSE field. This is necessary not only for the large population that lives in rural areas, but also because ruralities keep within them natural spaces that are vital to guard, preserve and defend for the benefit of the planet Earth. The need for a rural science education for rural spaces is a call for education to be relevant, meaningful, and enable school and community action to preserve or improve their ways of living -on their own account and in the manner they deem appropriate.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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