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STEM education for sustainability: An integrated and place-based pedagogical approach

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STEM education for sustainability: an integrated and place-based pedagogical approach

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For you, Bruno and Camilo, for a fairer, more equitable, and brighter future. In you, I see hope for the generations to come.

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ABSTRACT

Education for sustainability is critical nowadays, traditional educational settings need to adapt to the XXI century's challenges, and educational research has been growing in this direction during the last years. Sustainability challenges imply dealing with complexity, developing systemic thinking, and acquiring scientific reasoning and argumentation skills, to provide contextualized responses in diverse scenarios. The research and conceptual framework presented here was conducted from the south of Chile, in Wallmapu, the Mapuche people's land, the country's most significant indigenous population. The global trend of learning from real-world situations here acquires more importance, for its relationship with local indigenous knowledge is a crucial element to consider in education for sustainability.

Education in Science, Technology, Engineering, and Mathematics (STEM), is also a developing research topic. New frameworks and methodologies have expanded since the beginning of the XXI century worldwide, seeking a more coherent educational experience. The concept of integration, working based on real-world situations, and combining disciplines around specific and real problems has grown globally and needs to be observed and critically evaluated. There is a need for a better understanding about how to implement STEM education opportunities and which outcomes and benefits can emerge from these interventions.

This cumulative dissertation is based on two main scientific articles published in peer-reviewed journals and supported by five peer-reviewed book chapters written in English and Spanish as empirical and theoretical complementary materials to this work. It is situated at the intersection of STEM education and education for sustainability research and presents a framework based on international evidence and empirical research to conduct STEM Education for Sustainability (STEM4S) projects with children from ages 4 to 10. It starts with a review of broad international frameworks to understand the importance and the urgency of re-thinking pedagogical methods to confront future global scenarios. The second chapter summarizes a systematic review of the literature on Education for Sustainable Development, identifying three cornerstones to be considered for implementing STEM4S projects. The third section provides a conceptual framework centered on the learner experience: what does a STEM4S learning experience needs to be complete and successful? The frame divides the learners' experience into two key areas: scientific learning and students' motivation and engagement. The fourth chapter presents the leading research conducted for this dissertation. It starts by presenting the context of the project in the south of Chile, then presents a practical framework for implementing place-based STEM education opportunities based on a program implemented in 2019. This chapter finalizes with evidence about the importance of including the school's context to provide culturally relevant learning experiences, focusing on indigenous contexts, presenting a five-domain frame to promote a dialogue between scientific and indigenous knowledge.

MAIN AND ASSOCIATED PUBLICATIONS

MAIN PUBLICATIONS

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"Science and engineering produce 'know-how'; but 'know-how' is nothing by itself; it is a means without an end, a mere potentiality, an unfinished sentence. 'Know-how' is no more a culture than a piano is music. Can education help us to finish the sentence, to turn the potentiality into a reality to the benefit of man?" (Schumacher, 1973)

I. INTRODUCTION

The physicist and mathematician G.N.M Tyrell proposed the terms "convergent" and "divergent" to distinguish between problems that can be solved logically from those that are not. The positivist perspective, the reductionism, and hyper-specialization of science, sometimes fail to provide a practical solution, especially when facing complex challenges such as climate change or socio-ecological dilemmas. What can science education do about it? How can the schools become part of the solution? What happens in intercultural and indigenous contexts where diverse worldviews collide during the educational experience? This dissertation argues that Science, Technology, Engineering, and Mathematics (STEM) education can overcome an instrumentalist perspective on these challenges and provide spaces for transdisciplinary dialogue to affront the loss of meaning when facing problems that cannot be solved logically or that rely on ethical assumptions. The present framework provides an inductive and holistic perspective for early science education (from age 4 to 10), based on local challenges to affront sustainability dilemmas.

Sustainability and complex socio-ecological problems (e.g., climate change, land-use conflicts, responsible consumption, production) are usually divergent problems that cannot be easily solved instrumentally or logically. All the frameworks referring to the so-called challenges of the XXI century are aware of this complexity and the necessity to adapt the educational systems to understand that the instrumental or standardized scope in science education is neither sufficient nor an adequate path to follow. This framework provides evidence about which educational methodologies are needed to affront these divergent challenges and which skills, attitudes, and values need to be appropriately developed. The framework starts with broad international standards and frames on science education and skills for the XXI century, making an effort to land the global challenges of sustainability in kindergartens and schools. It emphasizes the importance of an inductive, integrated, and place-based scientific approach to give tools for constructive dialogue and the development of new localized knowledge in indigenous contexts, providing small solutions for sustainability challenges. In this way, it presents evidence on how to conduct learning experiences to develop basic argumentative and practical skills to attend to local sustainability issues and provide the possibility of a fruitful dialogue in indigenous and intercultural contexts.

Besides the necessity to re-think the scientific scope to affront the complex problems of the XXI century, there is also the need to reach all students with scientific education, particularly those who have been historically marginalized for their cultural distance to science. Scientific structure, logic, and scientific narratives are sometimes far away from real-world situations and could be considered external or imposed in regions with a colonial history. The idea of initiating a genuine dialogue and open discussion on the ethical and epistemological foundations of science is necessary to promote change and give tools to the new generations to affront a complex future scenario.

This project elaborates how integrated and context-relevant scientific education opportunities can raise students' motivation and develop agency towards sustainable futures. Besides, building early scientific reasoning and argumentation skills can give children the tools to provide relevant solutions to local challenges and critically evaluate their reality. This research observed when STEM education opens to local knowledge in indigenous contexts and helps understand how children, teachers, and the community can benefit from these initiatives. Finally, this dissertation presents a conceptual framework to guide further research in the area, providing ideas for further research to measure skills, motivation, and contextual aspects to consolidate what nowadays is an emergent field of research.

The idea of rethinking scientific education at an early stage implies not only proposing new methods to learn scientific content but also being aware of the importance of the ethical foundations of the scientific perspective, how permeable sciences are to the diversity of contexts, and assuming the ethical foundations behind the positivist scope. The scientific evidence about the limits of the earth, and the prediction about climate all over the globe, urges the necessity of building diverse and contextualized ethical foundations along with solid scientific skills and integrated educational opportunities.

This does not mean by any chance the idea of replacing the specialized for a holistic scope in science. It would be naïve to neglect the remarkable progress of scientific knowledge through the reductionist lens. However, understanding that the new challenges for science cannot be entirely solved by reducing complexity (since we are facing many divergent problems) opens a path for transdisciplinary dialogues and collective constructions with practitioners in diverse contexts.

At the school level, the idea of approaching divergent problems through active STEM methodologies and the development of inductive thinking to creatively affront real-world problems will be discussed in this paper. This framework contributes to the relatively new discussion on education for sustainability and STEM education, providing a theoretical basis for the implementation of coherent and inclusive STEM educational opportunities based on the latest articles, reviews, international frameworks, and the empirical work conducted after eight years of implementing a STEM education program in the south of Chile.

It starts with a review of broad international frameworks to understand the importance and the urgency of re-thinking pedagogical methods to confront future global scenarios. The second chapter summarizes a systematic review of the literature on Education for Sustainable Development, identifying three cornerstones to be considered for the implementation of STEM Education for Sustainability (STEM4S) projects. The third section provides a conceptual framework centered on the learner experience: what does a STEM4S learning experience needs to be complete and successful? The frame divides the learners' experience into two key areas: scientific learning and students' motivation and engagement. The fourth chapter presents the leading research conducted for this dissertation. It starts by presenting the context of the project in the south of Chile, then presents a practical framework for implementing place-based STEM education opportunities based on a program implemented in 2019. This chapter finalizes with evidence about the importance of including the school's context to provide culturally relevant learning experiences, focusing on indigenous contexts, presenting a five-domain frame to promote a dialogue between scientific and indigenous knowledge.

II. THEORETICAL FRAMEWORKS ON STEM EDUCATION FOR SUSTAINABILITY

STEM concepts: integration of knowledge and connection with the real world

STEM is a relatively new concept; its origins are related to the national science foundation in the US in the late 1990s, seeking to integrate disciplines and promote students' interest and skills in Science, Technology, Engineering, and Mathematics. For its ambitious proposal of integrating four complex domains, much ambiguity surrounds STEM approaches, with the risk of keeping working with disconnected subjects. However, a well-implemented integrated approach has the potential to solve global challenges of the modern world and help to build skills and mindsets prepared to affront the complex dilemmas of the XXI century (Kelley & Knowles, 2016).

International organizations have created new standards, frameworks, evaluations, and discussions on the future of education and the importance of preparing future generations for the new challenges of the XXI century. However, sometimes these discourses have difficulties arriving in the schools' realities, as it was stated in the report after the decade of education for sustainable development, saying that the more significant challenge has been to reach teachers and students, going beyond the policymaker level, connecting and transforming the educational experience (Buckler & Creech, 2014).

The literature on STEM education opportunities is mainly focused on secondary and higher education. Considering the importance of offering motivating learning experiences from an early stage, the framework presented here will focus on ages from 4 to 10. Based on empirical evidence and the specialized literature, it encompasses conceptual foundations, practical guidelines, and expected learning and motivational outcomes when presenting STEM education opportunities.

It is important to clarify that definitions of STEM education do consider not only natural and computational sciences but also social and behavioral sciences such as sociology, economics, psychology, and political sciences (Gonzalez & Kuenzi, 2012). The idea behind this complex integration is to connect different subjects starting from real-world situations, where students can learn from relevant and more stimulating experiences, encouraging critical thinking skills, problem-solving, and increasing retention (Stohlmann et al., 2012).

One key idea present in the majority of the STEM frameworks is the concept of integration. The straightforward idea is to integrate the different disciplines considered in the acronym STEM, including natural and social sciences. However, there is also a transversal focus on integrating educational opportunities to real-world situations, opening the schools to their context and contributing to implementing educational opportunities based on actual facts, with concrete results, tangible and valuable outputs (Moore et al., 2020). In the same direction, Rennie et al. (2020) proposed what they called a "worldly perspective" in STEM education, which means keeping a balance between STEM disciplinary and integrated knowledge, being careful not to fall into any of the extremes, and also maintaining the connection between global and local issues. Here the idea of real-world situations had to do with concrete local examples that should be carefully connected with global challenges.

The idea of a balance between disciplinary knowledge and integration also connects with the philosophical debate regarding science and complexity and modern science's capacity to confront new complex global challenges in diverse contexts. Haraway (1991) wrote an essay regarding the importance of situated knowledge to avoid race, gender, or ethnic biases always present in scientific endeavors. After revising several studies on primates and cyborgs, she argues that the "ideal" scientific process almost always fails when taken into practice (as many scientists will agree), and simplified models lose meaning when affronting complex real-world contexts.

The problem of complexity is critical in environmental education or any scientific activity involving nature. The idea of objectivity and understanding nature as a resource fails to incorporate worldviews and narratives where nature is alive and in constant interaction with humans. The scientific perspective in colonial contexts comes with hierarchical and imposed narratives about nature that have failed to generate a constructive dialogue toward sustainability. Thus, the idea of integration in STEM has to be not only dialogue among well-delimited academic disciplines but rather an open and systematic dialogue to incorporate diverse visions in the scientific process. Considering this path provides probably more chances to come to a better understanding of natural and social dynamics affecting the globe and its ecosystems.

Enrique Leff (2002), a Mexican sociologist who specialized in environmental education, also stresses the importance of environmental pedagogy. His radical perspective, based on critical pedagogies inspired by Freirean ideas (Freire, 1978, 1998), provides educational paths to replace modern rationality based on the principles of reductionism and objectivity present in modern science. The reductionist scope, in his perspective, has taken science to gain specialization and efficiency. However, it lost organicity and an ecological perspective to understand the social and natural phenomena. In other words, the overspecialization has successfully formed specialists in specific parts but loses the capacity to see the whole organism and lacks a clear picture of reality as a whole. This problem collides with indigenous perspectives, especially in their approach to nature and the environment. In this direction, Leff (2002) argues that modern rationality has conducted humanity to massive exploitation of natural resources and perpetuating social inequalities. From his perspective, the educational system can contribute to the urgent need for change in the way things are viewed and interpreted towards an "environmental knowledge" to replace the actual modern rationality that has caused an evident social and environmental degradation.

After several years of research and theoretical development, Leff (2002) proposes three main pillars of his pedagogical scope, which go hand in hand with the recent developments in STEM literature and the principles recently published by international educational frameworks (OECD, 2018a, 2018b). He proposes an environmental pedagogy, a pedagogy of complexity, and an interdisciplinary pedagogy, as the three main pillars for educational and social transformation. The considerable theoretical effort made by Leff recovers a history of pedagogical and interdisciplinary research in Latin America but lacks practical pedagogical approaches to it. The conceptual background of STEM4S projects presented in this framework opens a possibility for developing new educational initiatives. Here the possibility to open a genuine dialogue of knowledge from an early stage will be vital to enhancing the sense of purpose and the impact of educational processes in diverse contexts.

STEM place-based education and the development of inductive thinking

PISA mathematics 2021 framework emphasizes the idea of developing both inductive and deductive mathematical reasoning. It specifies the importance of statistical and probabilistic reasoning to develop inductive thinking competencies, especially when new generations need to process a lot of information and data and confront complex scenarios. Post-truth and conspiracy theories can quickly expand and become mainstream without these skills. Place-based education, scientific inquiry, and learning "about" and "with" the schools' context at an early stage can become a strategy to develop the basis of scientific argumentation without losing the sense of purpose or motivation since the activities are based on local problems and challenges.

The PISA 2021 framework also considers the idea of reasoning as the capacity to formulate, employ and interpret in a real-world situation as a central aspect of the assessment. Here, taking care of the context and solving contextualized problems is central, considering personal, social, occupational, and scientific contexts (OECD, 2018a). Integrated STEM education theoretical frameworks are relatively recent, but some general agreements can be underlined. Rennie et al. (2020) proposed a frame with two transversal balances that need to be considered for successful STEM activities. First, there is a need for a balance between disciplinary and integrated knowledge, and secondly, a particular concern on keeping a balance between local and global issues. In their proposal, there is a special emphasis on connecting educational experiences with the local reality and making connections with big ideas and global knowledge, enhancing students' relevance and engagement (L. Rennie et al., 2018).

In the same direction, Moore et al. (2020) made a systematic review of STEM frameworks taking a closer look at the emphasis on cognitive and sociocultural aspects. A significant predominance of cognitive frames was found, and the necessity for more integrated frameworks was claimed. In particular, regarding mathematics frameworks over the last fifty years, they identified a growing tendency of incorporating sociocultural aspects to mathematic learning in what the author called the emergence of the sociocultural. This growth has become crucial under the idea of learning for all. There is a growing need for theoretical networking. The authors conclude that more interdisciplinary and transdisciplinary frameworks are required to transit from understanding to unification.

There is a big challenge to connect curricular domain-specific knowledge with the transversal knowledge needed for the integration of STEM disciplines and to conduct research projects to deal with real-world situations. Here the OECD *Learning Compass 2030* (OECD, 2018b) proposes a general frame based on action under the name of "Anticipation-Action-Reflection". The role of sciences in the first anticipation step is critical, but just knowing how the future will be is not enough. Action and contextualized reflection are also critical to creating space for solution-based pedagogies. There is a global need for action starting at a very early stage, which aligns with the STEM tendencies. The framework presented here seeks to provide a solid conceptual basis for implementing educational opportunities in this direction.

Besides, the OECD *Learning Compass 2030* proposes four types of knowledge needed: disciplinary knowledge, procedural knowledge, epistemic knowledge, and interdisciplinary knowledge. Accordingly, in this proposal, the dominance of disciplinary knowledge –evident in standardized evaluations and international standards and frameworks – is declining and has become only one of four relevant domains.

Project-based and problem-based learning directly uses procedural knowledge when a complex problem challenges students. The focus on the procedure of project-based learning and the steps required for a proper inquiry are on the basis of these approaches (Bell, 2010). The characteristics and methods of the educational projects that will emerge under project or problem-based learning approaches need a clear path and justification for each step of the inquiry process and the technical solutions proposed as a result of the research process. For example, the use of maps and pictures of the different projects' steps helps significantly visualize why the project was implemented in one way or another. Those arguments help the students understand the nature of scientific knowledge and the importance of the process.

On the other hand, epistemology and epistemological knowledge had to be understood not just as an academic discussion regarding the nature of scientific disciplines considered in STEM education, but as a needed competence for the future and for understanding the nature of scientific thinking as a tool for trespassing the actual frontiers of technical and theoretical knowledge (Couso & Simarro, 2020). The idea behind this is that just as developers and not just users are needed in computer sciences, free thinkers and not just reproducers of delimited content are needed in the STEM subjects.

Finally, it is worth emphasizing the importance of the interdisciplinary and transdisciplinary nature of STEM. Here is key that none of the specific disciplines lead the educational experience. Instead, it is essential to have a natural integration between disciplines and other non-academic knowledge relevant to the context of the educational setting. Therefore, the open dialogue and the diversity of methods to incorporate the context to the educational experience are very relevant, along with the focus on the process and the epistemic discussion.

The UNESCO 2030 framework for action made a clear call to transform the educational experiences and provide genuine and concrete opportunities to create more inclusive, high-quality, and lifelong learning, putting particular focus on innovation in STEM (UNICEF, 2016). The present framework will clarify the conceptual and theoretical underpinnings for the implementation of STEM4S projects, with a Latin American scope based on empirical evidence in the Chilean context.

III. SYSTEMATIC LITERATURE REVIEW: CORNERSTONES OF STEM4S PROJECTS

At the beginning of this Ph.D. project, a systematic review of the literature was conducted and published as a central part of the research process (Bascopé et al., 2019). Considering the global emergency for a change in educational settings, it was crucial to understand what international research suggests about conducting education for sustainability learning experiences as a first step to consolidating the concept of STEM4S projects and their operation. As a result, Fifty-six (56) peer-reviewed articles were revised to arrive at three main cornerstones regarding education for sustainability, highlighting the centrality of integrated science and connection with the local values and practices.

The scientific process behind STEM4S projects has an inductive structure, starting from global issues, understanding how these significant issues are manifested in their local environments, and finding multiple solutions or ways to tackle these problems using STEM methodologies such as design thinking or project-based learning. Therefore, we defined these projects as a process starting from divergence, using complex macro concepts —such as sustainability, socioecological resilience, climate change, or the sustainable development goals— to convergence, focusing on specific local issues and the promotion of precise skills attitudes, and values related with the topic.

The development of XXI-century skills is associated with unsolved situations, preparation for changing futures, and adaptation to new climatic scenarios. The structure of STEM4S projects attempts to create an educational situation that connects children with new sustainable futures from an early stage, with a clear scientific focus but constantly connected to their local reality. The importance of learning from real-world situations is evident here, as mentioned in the revised international frameworks. For example, recent educational research has emphasized the development of creativity as a central element and one essential skill for the XXI century (Bell, 2010). Vartanian et al. (2003) support a relationship between inductive thinking, problem-solving, and creativity. In their view, the capacity to explore and think on multiple paths and possible solutions is related to more creative minds. STEM4S projects are an invitation to think about creative solutions with a precise method to find new ways toward sustainable futures.

Accordingly, the present framework is not about domain-specific science topics but interdisciplinary science projects. This domain-generality is not restricted to specific domains but should motivate students and connect them with their reality. It also opens the possibility of discussing complex real-world situations at an earlier stage, opening to the children the possibility to raise their opinion and create scientifically-based ideas, propose local solutions, and connect with their local reality. In this sense, the proposed framework has double importance. First, it connects children with scientific thinking to achieve domain-general skills, as will be examined in the following sections. Second, it also plays a role in empowering them to take action, profoundly impacting their motivation.

Three conceptual pillars for the implementation of STEM4S projects were found after a systematic review of the literature on education for sustainable development at an early stage (Bascopé et al., 2019). They can be summarized as follows:

1. *Value-oriented projects*

STEM4S projects must be situated in a defined value system within a specific historical context and actual social circumstances that cannot be avoided. In defining the objectives, it is crucial to remark which values towards sustainability are being formed and promote reflection on the actual circumstances and the future consequences if no action is taken. Here it is essential to think not only about ecological or conservational values towards the natural environment but also about values regarding democracy, diversity of perspective, and social justice, among other values related to sustainable citizenship (Hägglund & Samuelsson, 2009; Luff, 2018).

Bascopé et al. (2019) remark on the importance of forming in both "ethics" and "aesthetics" values, values for democratic citizenship, combining both individual and collective rights, protection of the commons, interdependence, and connection with nature, respect for diverse worldviews among other are essential ethical values (Elliott & Young, 2016; Hägglund & Samuelsson, 2009; Wals, 2017). Nevertheless, forming "aesthetic" values is also key to creating a long last bounding with natural and cultural contexts and a positive attitude towards life. Moreover, aesthetics as a meta-structure helps develop connections with distant objects, activating the learning process through intuition and creativity and fostering innovation. Therefore, developing aesthetic values impacts the cognitive development necessary to forge a sense of belonging with the local environment (Eernstman & Wals, 2013; Gray & Birrell, 2015; Vecchi, 2010).

It is also important to maintain openness to other worldviews, to practical, local, and traditional knowledge and perspectives about the environment and society. It is not just about inclusion or consideration for diversity. It is about opening the scientific lens to perspectives that have been historically marginalized from the mainstream discourses and narratives, leaving behind relevant practices and knowledge related to sustainability (Leff, 2002). When applied to socio-ecological challenges or conflicts that still prevail in many territories, the actual consideration of a transdisciplinary scope is needed, especially in colonized contexts such as Latin America.

2. *Outdoor/place-based education*

First, a crucial cornerstone is to consider feasible and context-relevant projects. The connection with local challenges, problems, and dilemmas is essential. Especially at an early stage, making learning visible in everyday routines and having children be aware of their making a difference and contributing to their communities is crucial. It also means learning "from and about local communities," building what, in terms of Duhn (2012), is a “pedagogy of place”, generating conditions to establish a fruitful dialogue and co-learning with community actors in a bidirectional exchange (Bascopé et al., 2019; Duhn, 2012; Zachariou & Symeou, 2009).

International research also emphasizes the importance of providing hands-on and outdoor experiences. The encounter with nature and the local community has been widely supported in the literature for its impact on future attitudes towards the environment and local culture and for the power that it has to engage students in learning activities (Nigh & Bertely, 2018; Sykes, 2008; Tilbury & Wortman, 2008; Zachariou & Symeou, 2009). Besides, to build a project based on local problems of the educational institution's surroundings is imperative to provide direct contact with the place where the project is conducted, to sensitize with the specific problem or challenge, to gather valuable information, and to conduct a proper empirical research project (Green, 2015)

3. *STEM integrated science scope*

It is crucial to keep in mind that besides the direct impact outdoor education has, free exploration and nature experiences are not enough if we want to start building capacities to affront complex future scenarios. Starting bridging STEM competence from an early stage is key to fostering interest in learning, building scientific capacities, and systemic thinking to affront complex problems (Campbell et al., 2018). The proper conduction of scientific-based activities helps form future agents of change, and fostering agency is widely recognized as key in early childhood education (Caiman & Lundegard, 2014; J. M. Davis, 2015; Sawitri, 2017). A problem-based approach that helps develop scientific competence in a constructivist fashion, using an interdisciplinary focus to affront the specific problem defined. It means finding different curricular objectives from diverse assignments to contribute to the different objectives and stages of the project (Bascopé et al., 2019).

Another crucial aspect of the STEM scope implies taking students' interest and fostering them to make decisions. Therefore, involving students in the ideation of the project from the beginning is very important to generate capacities to build relevant questions and define relevant problems, make them be part of the project, and engage them (Mitchell et al., 2009). Meaning generating activities with children to define the problem, generate research questions, build the research objectives, plan the fieldwork and analysis activities, and think about possible solutions and contributions to the problem. This participative and place-based scope can contribute to building solid scientific capacities and motivation in students, as will be specified in the following section.

IV. THE LEARNING PROCESS: EXPECTED EFFECTS OF STEM4S PROJECTS

To understand the learning process during the implementation of STEM4S projects, this chapter reviews research based on two central aspects of this process: 1) the development of scientific reasoning and argumentation skills, and 2) the effects on motivation and engagement.

STEM4S and scientific reasoning and argumentation

Moore et al. (2020) made a systematic review of the scientific literature about STEM integration to help understand how this integration is defined, conceptualized, and operationalized in the literature. It reaches some extensive agreements on the importance of integrating STEM and real-world situations and the importance of integration by connecting with transversal skills and ideas. After the review, the authors highlight the importance of scientific reasoning and argumentation (SRA) as a cross-discipline big idea to connect and integrate STEM disciplines.

The Piagetian perspective on the development of scientific reasoning is a common starting point in discussing how SRA is built from childhood to adolescence (Inhelder & Piaget, 1958). However, the view of kids as little scientists with natural curiosity and as active researchers of their surroundings has been approached from different angles and has given this foundational theory a new impulse in the latter years, discarding some propositions but maintaining basic developmental ideas described above.

A "second impulse" of Piaget's theory can be identified in the recent literature on Early Childhood Education, starting near the 2000s, with an increase in Piaget's citations. This growth does not mean a wholly aligned vision regarding its approach, but it considers some critical views of the Piagetian basics structures and processes to understand cognitive structures and skills as a baseline to scaffold scientific reasoning and argumentation (Kuhn et al., 1988).

Two dimensions can be found crucial in Piaget's theory, the structuralist dimension (developmental stages) and the constructivist dimension. The developmental stages have been widely criticized for their lack of flexibility and several counterfactual empirical results, which indicate the early development of abilities or no development of the expected skills at the adolescent stage, bringing questions about these structures and their usability (Sodian, 2018). Nowadays, the discussion goes more into the constructivist dimension of Piaget's legacy.

On the other hand, *construction* is both constrained internally (cognitive, domain specificity, AToM, Intelligence) and externally (sociocultural approach). Although, at an early stage, there is a blurry line of differentiation between internal and external constraints, and actions can be influenced by both aspects depending on the prior experiences of the children, here the importance of considering both aspects for a more comprehensive contribution of research to policy and teacher practice.

From the cognitive perspective, literature has transited from domain-specific skills and their importance as a starting point to build general scientific skills to a debate that tends to turn the discussion the other way around, emphasizing, revealing, and understanding those general thinking structures that scaffold the development of more science-related domain-specific knowledge. For example, the importance of "encoding", "strategy use", and metacognition in the scientific process are considered basic transversal skills for scientific reasoning. Also, the capacity for experimentation, data interpretation, and understanding of the nature of sciences have been characterized as essential features related to the capacity for hypothesis making and the differentiation of evidence and theory (Koerber et al., 2015; Koerber & Osterhaus, 2019; Osterhaus et al., 2020; Zimmerman, 2007).

Due to the multiple disciplines involved in STEM education and the diverse specific skills of the different disciplines, there is a need for frameworks that work on transversal skills and competencies (Couso & Simarro, 2020). There are some attempts to find these general scientific skills linked to the four disciplines in the acronym. The advantage of starting at an early stage is that the specificity of skills or content from each separate discipline is still to be developed in further steps. Thus, there is an opportunity to work on more general concepts that will be useful in the future to learn more specific topics.

Based on Koerber and Osterhaus (2019), we present three critical cross-discipline skills to be considered when implementing STEM4S projects. Data analysis and distinguishing data from opinion is the first important step. Children need to interpret simple patterns of covariation data concerning a hypothesis and understand that confounded data does not warrant a conclusion, and practical experiences of analysis can help in this direction. Evidence shows that young children may selectively attend to data that confirms their hypothesis or fail to understand that data must not be confounded (Chinn & Brewer, 1993; Reiss et al., 2011; Saffran et al., 2019).

Following the revision made by Koerber and Osterhaus, (2019) for the construction of an inventory to measure initial scientific skills in young children, they also distinguish elements of the nature of sciences, where children need to understand that scientists make considerable efforts to understand and explain the world, in opposition to the idea of just collecting facts about reality. Children also need to understand that scientists systematically perceive the world to produce systematic evidence and understand the importance of the scientific process. Children often fail to recognize the systematic nature of the scientific approach or do not fully understand the importance of the process since they have never practiced science. There is also new evidence about the importance of epistemological understanding of science at the primary level since it predicts the development of experimentation skills (Osterhaus et al., 2017)

This connects with the third critical SRA competence, the experimentation skills. First, children need to be able to design experiments that allow for a conclusive test of the hypothesis. Here we refer to basic and straightforward experiments at a younger age that will increase complexity over the years. Secondly, kids need to be able to apply the control-of-variable strategy and master the principles of variable isolation and control. Finally, since, in many cases, children tend to think of experimentation in terms of effect production instead of corroboration (Sodian et al., 1991), they also might have difficulties with the control-of-variable strategy and manipulating several variables at a time or do not contrast the focal variable, failing in the creation of valuable experiments (Bullock & Ziegler, 1999; Chen & Klahr, 1999).

From the sociocultural perspective, research has progressively transited from frameworks that did not consider the socio-cultural context to studies that consider epistemic notions and preconceptions. Starting from experiments conducted only with cognitive variables in the equation to more complex studies that make links with the nature of sciences, language, symbols, and also the importance of the interaction with the natural and social environment as a strategy to foster meaningful and active learning experiences (Moore et al., 2020). The importance of connecting the scientific tasks with everyday life experiences and conducting activities that connect the scientific perspective with the cultural background (e.g., common set of values towards social good, social justice, environmental activism, community service, sustainability issues) can be a way to build a solid scientific basis and to promote epistemic justice for those coming from disadvantage contexts (Fricker, 2007).

Holistic approaches to teaching sciences, to foster scientific thinking based on local challenges and starting from the kids' perspective, can be postulated as an actual consensual method to foster basic SRA skills. Interdisciplinary perspectives, problem-solving-oriented tasks, and place-based research approaches can be suitable options that cave to found more space in the kindergarten and schools to build a solid scientific basis and conscious citizens (Bascopé et al., 2019; MacDonald et al., 2020).

Real-world problems in the community: students' motivation and engagement

How can we transit from real-world situations to genuine connections with the local community, and how can this step enhance students' motivation and engagement? Project and problem-based learning proved to positively impact student engagement, mainly when the project is applied to the local community (Bell, 2010; Brundiers & Wiek, 2013; Mitchell et al., 2009; Murtaza & Mahmood, 2018). This section will explain how the STEM4S approach can generate engagement and action and thus, develop agency in the students.

Agency can be understood as an individualistic approach, an internal capacity for personal choice, and a self-directed capacity framed on liberal ideas. But as the literature shows, it can also become a collective and cooperative competence, especially at an early stage, elaborating a notion of agency as an open-ended, situated, and transactional process (Caiman & Lundegard, 2014)

In Latin America, the history of colonialism and the imposition of external and not situated models, solutions, technologies, and procedures give more urgency to the need to train and develop students' agency. Paternalist and asistencialist policies, actions, and discourses proved to fail in Latin America. They often disempowered communities and did not give the new generations the capacity to act and transform their local realities with action and ideas situated and collectively built. Pluralism and the incorporation of a diversity of different perspectives to tackle the complex sustainability problems is crucial to empower new generations, avoiding raising passive citizens waiting for the state or other authorities to provide external solutions to their challenges.

> *"Likewise, Ostrom (2014) argues for action at different scales, from 'the household to the globe' (p. 116), because all scales would also benefit from solving the severe threats they are faced with. Moreover, she points out that top-down initiatives from global or even national administrations suffer with some disadvantages. Firstly, they are likely to take too long before they produce visible benefits. Secondly, they are prone to many counter-productive side effects such as free riding and a simple exportation from one location to another of behavior that produces more risk than it solves (Ostrom, 2014)."* (Sass et al., 2020, p)

Children need to understand the complexity of socioecological or climatic problems and find diverse ways to be an active part of the solution. Caiman and Lundegard (2014) claim the importance of agency for two reasons. First, for its importance for democracy and pluralism, giving children the possibility to take the initiative, give directions and make their own decisions. Second, they also provide empirical examples of how the process of anticipation needed for agency is a process of mutual and cooperative participation.

Sass et al. (2020) propose a model of action competence that includes three principal aspects: willingness, knowledge and skills, and confidence. Willingness has to do with autonomous motivation and drive. The idea of intrinsic motivation to drive action is crucial in this frame. Knowledge has to do with knowledge about the specific topics involved in the action, not fragmented but understanding the interconnection between the different factors involved in the field of action. Also, knowledge about the social norms in which the action will take place involves a reflection on the adequacy of our norms in society and the capacity to reflect on the adequacy of one's thoughts and actions (Bandura, 2001). Furthermore, here we refer not only to action to tackle environmental problems but also understand the political implications of their actions and the interconnectedness of the different spheres. Thus, it is not just about presenting scientific or technical solutions to specific environmental problems but also understanding that their activities take place in a situated frame of social norms and the importance of collective action.

Local action-based STEM projects can help to achieve environmentally aware behaviors. Concerning this topic, there is also research involving early connection with nature and its benefits for child development and nature conservation. Chawla and Gould (2020) made a systematic review on children and youth's connection with nature and coping with environmental loss. The evidence is clear regarding the importance of nature experiences to build a solid connection with nature, positive effects on cognitive performance, pro-environmental behaviors, and a sense of hope regarding the future. They also found differences in the relationship with nature depending on the cultural background: While indigenous outdoors activities involved a direct relationship with other species, in activities such as hunting, fishing, collecting berries, harvesting medicinal plants, in European and American families, nature was more of a landscape mainly in sports activities such as baseball, boating, or biking (Bang et al., 2015). While the first families understood relationships among species and interacted directly with nature, the others enjoyed nature as a landscape or background. Here, learning about diverse ways of relationship with nature is key to building a solid sense of belonging and promoting action toward sustainability.

Thus, agency is directly related to an active engagement with the environment. Therefore, pedagogical innovations and resources for STEM4S projects must be open to agentic heterogeneity and understanding of how cultural backgrounds are decisive in shaping the relationship with our environment. Hence, it is also critical to understand the socio-cultural construction of agency, how actions take place in context, and how to provide inclusive STEM opportunities, especially in the Latinamerican context, to provide a fruitful dialogue of knowledge.

V. THE PRESENT RESEARCH: STEM4S PROJECTS IN THE ARAUCANÍA REGION

Empirical research on education for sustainable development is a growing field, but recent literature reviews claim the need for more systematic and empirical studies (J. Davis, 2009; Güler Yıldız et al., 2021; Somerville & Williams, 2015). This doctoral project aims to connect two emergent topics in educational research: education for sustainability and STEM in early childhood and primary education. The main outcomes of the empirical research conducted in the south of Chile are presented in this section. Likewise, the primary conceptual outcomes from the empirical research process are described, emphasizing the importance of place-based education, especially in indigenous contexts, such as the present research context.

This chapter condenses results published in scientific journals and peer-reviewed book chapters. It starts with a description of the context where this research project was implemented. After that, a description of the research projects implemented in schools and kindergartens is shown to understand the different interventions' dynamics, steps, and conditions. Then, after presenting the foundations of culturally-relevant STEM learning, the chapter ends with presenting a five-domain framework for the implementation of STEM4S projects in an indigenous context, considering the importance of the Mapuche people in the field of research.

The context for the emergence of STEM4S projects

The schools and teachers who participated in the project are located in Araucanía, Los Rios, and Los Lagos regions. This area is known for its national parks and natural sceneries, as well as being the homeland of the Mapuche people, Chile's biggest indigenous group, who are currently involved in a political struggle. In this territory, as in contemporary Latin America, historical challenges are now compounded by global challenges, such as climate change and a growing crisis of democracy. Moreover, the environmental challenges (e.g., water scarcity, deforestation, loss of biodiversity) are closely related to historical land-use practices and ethnic conflict. Therefore, environmental and intercultural issues are interlinked and at the heart of the social, political, and economic agenda. Besides, the region is characterized by a relatively high proportion of indigenous and rural populations and high poverty rates relative to the rest of the country.

The project was led by Pontificia Universidad Católica de Chile in its campus located in Villarrica. The Campus offers undergraduate degrees in early childhood education and primary education, giving educational opportunities for pre-service and in-service teacher training in the region. Along with the university, several national and international partners have cooperated with the project, including the private and public sectors.

The objective was to provide inquiry-based learning opportunities and support teachers in using and understanding constructivist problem-oriented approaches. The programs included environmental and intercultural education topics that can be addressed from a STEM perspective and methodological tools for the implementation. Having already trained more than 400 teachers, following and monitoring 60 schools during the implementation and producing educational resources, the University is conducting empirical research to understand the learners' experience and the key elements to consider to build a solid program on STEM education for sustainability.

The present framework refers to a specific kind of intervention that was implemented in 2019 in schools of the region in the context of a project called "Epu Trokin Kimün", an expression that in Mapuzungun —the Mapuche Language— means "dialogue/exchange between two kinds of knowledge" (Bascopé et al., 2021). The primary purpose of this initiative was to train teachers in project-based learning methodologies to tackle local problems that should be addressed using scientific and local sources of knowledge. The projects lasted from one semester to one year, depending on the school, and were surveyed by a team from the University during the whole period, raising specific information about the projects and their implementation (Bascopé & Reiss, 2021).

The aims and structure of the implemented projects will be described in the following paragraphs to help land the big international frameworks and adequately understand the educational experiences framed in this paper.

Project-Based Operational Model: Fostering Local and Scientific Knowledge

Following an extensive literature review of the international experience and knowledge gained during school projects, a model for the implementation of relevant place-based research projects was built, as shown in Figure 1 (Bascopé et al., 2021). The model is divided into four operational steps. The spiral path represents the divergence from the first stages, initially tackling local complex sustainability challenges, converging towards specific curriculum-related activities, and finally achieving one practical local solution. This inductive research approach started with exploring the schools' contexts, connecting complex local challenges with global problems and the national curriculum, intending to learn about the schools' context and generate the conditions for a dialogue of knowledge. The main constraints and opportunities found during the implementation were published in the chapter written by Bascopé et al. (2021).

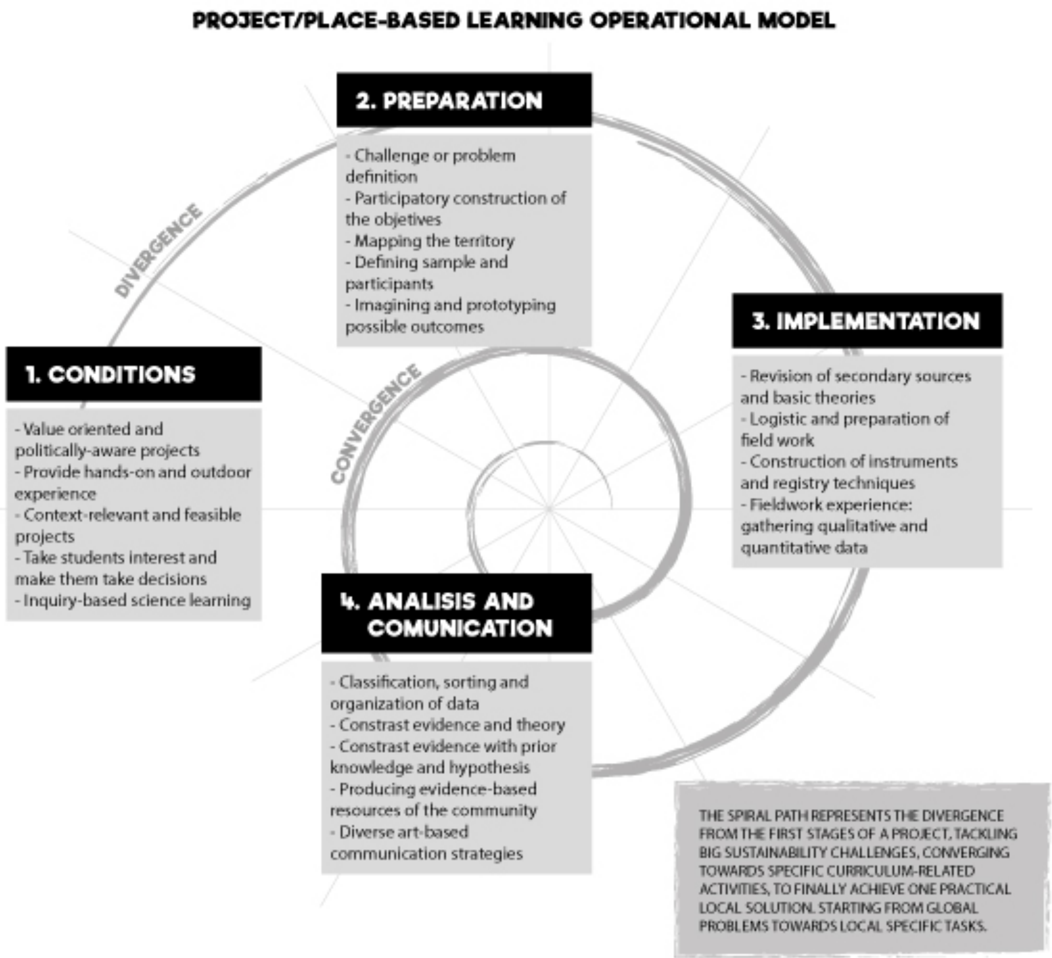

Figure 1. Project-based learning operational model. Source: (Bascopé et al., 2021)

1. Conditions for Implementation

This step can be considered step zero as a checklist needed before starting any project on STEM education for sustainability. Five conditions were considered necessary for the project implementation: 1) promote inquiry-based science learning, 2) devise context relevant and feasible projects, 3) take students' interests and invite them to make decisions, 4) Provide hands-on and outdoor experiences, and 5) build value-oriented and politically aware projects.

Students and teachers had to compromise and participate in constructing context-relevant and feasible projects. Teachers recognized local knowledge, thus connecting themselves with local problems. Children were encouraged to be aware of and contribute to their communities and develop value-oriented and politically-aware projects in collaboration with their teachers.

2. Preparation

The preparation step was implemented collaboratively between teachers and researchers from the University. It consisted of two workshops at the beginning of the school year, the first one to understand the conditions and needs of the school and its context using participatory methodologies. Here the teachers ended with a group of well-structured research questions to discuss and refine with their students. After this step, another workshop was prepared to build a research plan collaborating with school colleagues and university researchers. Here maps of the school's territory at different scales were used to look for partners and plan the fieldwork. Moreover, the sample was defined, and possible products and solutions associated with the research process were visualized. Finally, the workshop ended with a complete schedule of the project, assuming responsibilities for each member of the participating schools.

This step was essential to building a consistent and contextualized project. Teachers and students were familiar with their territories and local knowledge but found it challenging to convert this into a research project with a defined problem and objectives. The collaboration among teachers and active researchers from different backgrounds was highly appreciated and crucial for this step of the project.

3. Implementation

The implementation stage of the project had to do with the preparation of the fieldwork experience, including not only all the intern procedures, paperwork, and logistics to achieve the different outdoor activities, but also the preparation of research instruments (e.g., observation rubrics, interview guidelines, fieldwork note pads) and all the necessary material for a proper data gathering. Before starting the fieldwork, it was also recommended to look at secondary sources for the selected problem to have an idea of the previous work on the topic, identifying gaps and possibilities. Depending on the methodology applied, the projects always had one or more fieldwork experiences in the local context.

Implementation was one of the more prosperous stages of the projects. Teachers discovered learning opportunities outside the classroom, in the territory, while children expressed a strong interest in outdoor experiences, especially those in which they interacted with nature and the community at the same time. The weakest part of the process was the registry process and the preparation of instruments used to gather information during the fieldwork (e.g., rubrics, interviews' guidelines, surveys). Teachers and children faced difficulties choosing methods and registering helpful information for further analysis, probably due to a lack of inquiry skills and research experience (Bascopé et al., 2021).

4. Analysis and Communication

This final stage involved analyzing the information gathered during the fieldwork and producing and communicating the solution that resulted from the project. Regarding the analysis, considering the age group, it was suggested to the teachers to address activities to differentiate facts from opinions, the idea of proving or rejecting the initial hypothesis, and doing basic experiments to understand the problem and its context. The fundamental practical skills for doing sciences were at the center of this stage.

However, a central aspect of these projects was the connection to the local reality and the response to local challenges and problems. So, there was a clear focus on small solutions based on the research process. Prototyping and producing the final solutions for the projects were also considered in this final step. The projects ended with a regional showcase led by the kids in three different country regions. Children were highly innovative in the strategies they chose to represent their results. For example, there were musical and artistic performances, a mobile nursery suitcase, leaf-shaped keychains, and books recipes, demonstrating various ways to disseminate results. These examples showed a desire to use integrative and comprehensive ways to present research results (Bascopé et al., 2021; Bascopé & Reiss, 2021).

The final step was about communicating and finding innovative ways to showcase and share results with the internal and external school community. This was the opportunity to reach a greater audience and share the solutions with the real world. Planning and implementing good communication strategies has proven to be an effective way to close a research process with meaningful experiences and a clear sense of purpose. Here is where the effectiveness and usefulness of the educational process are at stake and where STEM applications are at glance.

This summary of the projects' structure, with the main objectives and activities held in each step, aimed to clarify the practical ground on which this framework was built. The idea of STEM4S projects is broad and involves a great variety of possible educational settings, so referring to STEM4S projects, this practical frame gives an idea of the structure and conditions to consider. However, besides these practical stages, some other conceptual cornerstones are needed to specify, especially considering the latest evidence and research in the area.

Place-Based Stem Education: Promoting Culturally Relevant Learning Opportunities

To work in STEM4S projects, it is crucial to define a concrete framework to establish a dialogue between the school and its context. This proposal emphasizes the importance of culturally relevant learning following the ideas of Gloria Ladson Billings (Ladson-Billings, 1995). She is recognized as one of the leaders of culturally relevant learning in the United States, and some of the foundations of her ideas can be implemented elsewhere. Due to the nature of STEM4S projects, where outdoor and nature experiences are at the center, this section refers to the discussion and the importance of community involvement for the student's learning process.

Developing culturally relevant learning opportunities implies being aware of the cultural differences inside the classroom and considering the context where the school is located. Following Ladson-Billing's framework, it has a triple focus, addressing academic success, cultural competencies, and sociopolitical awareness (Ladson-Billings, 1995). To build awareness, the sociopolitical context and the cultural characteristics inside of the classroom have to be explicitly considered. In this sense, referring to student-centered opportunities means culturally aware learning opportunities. Education here is seen as a critical activity that seeks to make the world a more just and equitable place. So the concept of effectiveness does not limit to academic achievement but also the inclusion of families and community-making (Magee et al., 2020).

There have been theoretical approaches with a specific focus on STEM education. Magee et al. (2020) propose a way to conceptualize this approach in practice. She argues that understanding the theoretical underpinnings of culturally relevant STEM pedagogy is crucial, but if those are not translated to effective classroom practices, they do little good. She proposes three critical themes for implementing STEM pedagogies that align with this framework: 1) students' engagement and performance, 2) teaching practices, dispositions, and training, and 3) curricular resources, giving specific practical examples for the implementation.

Some of the mentioned examples in Magee et al. (2020) include situations were putting the focus on students' engagement was as important as achievement, comprehending this achievement beyond test scores, connecting with the community, cultural practices, arts, local activities, honoring students' perceptions of reality, working through difficult situations with commitment and care, prioritizing students' needs and choices, among others. In the case of STEM4S educational opportunities fit with this focus. It enhances the importance of sociocultural topics in STEM, focusing on outdoor nature experiences and community involvement.

According to Ferreira, Ryan, and Tilbury (2006), Education for sustainability supports a systematic "whole institution approach" that focuses on the whole operation of the educational facility and takes into account not just the work of early childhood educators or primary teachers, but also school leaders, district or state leaders, or other decision-makers at the management level or ministry of education.

In this spirit, STEM4S should promote inquiry-based learning and scientific thinking and practice promoting learner-centered instruction that allows for exploratory, action-oriented, reflective, and transformative learning in a transdisciplinary fashion. Advocating a "whole-institution" approach that focuses on the educational facility's systemic development toward quality education and sustainability and the role of management at the school, state, and federal levels. It should encourage autonomous thinking and responsible action in the learner context and the institution's social and environmental context by allowing students to implement and experience meaningful improvements in their community, even on a micro-level. It should also stimulate critical reflection on values, recognize complexity, promote diversity of views and change of perspectives, and strengthen evidence-based and reasoned argumentation. Finally, it should empower present and future generations to use STEM skills and reflective reasoning to solve complex sustainability problems (Pahnke et al., 2019).

So, regarding STEM4S experiences, the impulse given by the international frameworks to connect science and mathematics to real-world situations demands to create a direct connection with the school's natural and social environment. It is more challenging since it requires not just learning about distant real-world scenarios but working collaboratively with local actors in actual and proximate challenges that directly affect the student and their community.

Constructive dialogue with Mapuche knowledge

Mapuche means people (che) of the land (Mapu). Like those of many Amerindian and eastern civilizations, their worldviews and traditional practices are essentially ecological, recognizing humans, plants, bodies of water, and other beings as co-inhabitants. (Rozzi, 2013). Opening the scholar culture and the STEM education research in specific, making it permeable to these diverse worldviews under a broad understanding of what STEM education means, can make a big difference in the challenge of sustainability and environmental degradation.

When talking about Mapuche learning and worldviews, it is vital to avoid falling into stereotypes and essentialist views about their traditions and ways of living. Nevertheless, there are some previous efforts to establish a constructive dialogue between scientific education and Mapuche learning traditions. Torres et al. (2011) stress the importance of a sociocultural perspective on learning, which puts on the center the idea of learning by doing to incorporate culturally relevant knowledge. Knowledge about nature and society are embedded in social memory and transmitted from generation to generation, and new pedagogical approaches can be an opportunity to incorporate new sources to establish a fruitful respectful dialogue.

Studies focused on Mapuche ways of learning have observed interactions between learners and teachers, finding that the teacher figure does not exist. Instead, there is an image of wise people who share knowledge through interaction in outdoor spaces and everyday life situations rather than by formal means (Quilaqueo et al., 2010; Quintriqueo & Torres, 2012). Parents and adults are knowledge managers in children's environment and model how to put knowledge into practice, either through play or in the daily chores inherent in community and home life (King & Schielmann, 2004; Llanquinao, 2009). In this adult-child relationship, the autonomy of children in resolving the situations they face is privileged, and few instructions or orders are observed (Ibáñez-Salgado, 2015).

School dynamics can dramatically break local epistemologies, approaches to learning, and the relationship with adults, setting new structures under the umbrella of "good behavior". As a result, the school contents can lose their experiential character, often becoming distant, odd, and foreign to the students. Teachers have a central role in the classroom, giving orders and shaping the practices and ways of learning in the classroom. However, this situation can be remedied and redirected by the school by using educational approaches that integrate students' prior knowledge and learning dynamics in their cultural systems. (Bascopé & Gutiérrez, 2019; Bascopé & Reiss, 2021). Here STEM4S projects with the previously defined characteristics can establish a path to promote culturally relevant learning and create the spaces for a dialogic and constructive learning experience for the students to confront complex challenges in their daily lives, both during their school experience and in their future.

In this direction, we developed a five-dimensional framework to build STEM4S projects (Bascopé & Caniguan, 2016). After proving its usability during the ethnographic work in 2019, a summary of this five-domain framework was published (Bascopé & Reiss, 2021).

To build this five-domain framework, we conducted comprehensive fieldwork with a group of five schools and their external communities in 2014 and 2015, covering different territories of the Araucanía region in Chile. Using a qualitative methodology based on in-depth interviews with teachers, traditional educators, families, and indigenous community leaders, we aimed to find suitable sources and topics of local knowledge that might be included in a scientific inquiry-based learning curriculum (Bascopé & Caniguan, 2016). The five domains were produced after a systematization and coding process and compared to the Chilean national curriculum to examine curricular objective coverage at the primary level, revealing many objectives per dimension across the primary curriculum. The following is an overview of how these domains apply to STEM4S projects, based on the experience of 2019:

1. Health and the human body:

This domain connects with several UN sustainability goals, being a fruitful space for connecting global with local challenges. Traditional medicine and knowledge about medicinal herbs are used daily in Mapuche communities, with profound knowledge connected to the native forests and traditional green gardening practices. Therefore, recognizing these traditional sources of knowledge to establish a dialogue with the curricular objectives is a fruitful field to start STEM4S projects. This domain's contents can be developed both inside and outside of the classroom, and they can be supplemented with specific knowledge of native flora and its peculiarities. The chemical processes behind the preparation of the medicines, the importance of the relationship between species for socio-ecological systems' conservation, and the historical struggles associated with the perpetuation of this ancient knowledge are just some examples of the fruitfulness of this domain.

2. Traditional foods and culinary processes:

Cooking recipes and food preparations represent another area for profound dialogue between scientific and indigenous knowledge. Processes of dehydration, fermentation, and decomposition of food are linked with different flavors, textures, and techniques that allow food preservation. The knowledge present in the kitchen is intrinsically connected with family traditions and everyday routines. It is a trendy topic for the schools' external community, especially to generate an intergenerational dialogue with a significant presence of grandparents. The elders can share their history and the reasons behind the recipes and dishes that have started to be forgotten due to the scarcity of the ingredients or the replacement of familiar traditions and rituals. Sustainable food consumption and production are at stake, along with health and alimentary sovereignty topics that can be explored and discussed in this domain. It provides a solid ground for creating STEM4S projects giving diverse routes for exploration, all of those with the potential of gaining interest and producing impacts in the community.

3. Crafts and tools manufacture:

Tool manufacture, goldsmithing, and other crafts are connected with local traditions and the ongoing work and expertise of parents in the school community. For example, the dyeing of wool with vegetable species is a traditional practice, and it connects the importance of the local environmental conditions with ancestral sources of know-how that have been losing their strength as working opportunities for the new generations. Same with all the locally relevant manufacturing techniques that use local resources. This is another fruitful field for starting STEM4S projects. It connects local environmental challenges with local and scientific knowledge and provides an opportunity to revitalize ancestral techniques renewing their value and providing opportunities and start new endeavors based on a solid research path conducted by the school in collaboration with the local community.

4. Ecosystems and agriculture:

This could be the more straightforward domain for the implementation of STEM4S projects. It is not about the blind incorporation of traditional agricultural practices but rather about exploring local practices with all the accumulated knowledge on agroecology and sustainable management. Local traditions can be connected with modern agroecological perspectives, allowing learning about traditional practices and combining them with other sources to improve land use and diminish the impacts that traditional practices might have on the ecosystems. The traditional conservation focus of environmental education, which has been criticized in the literature as a "not good enough scope", can be combined with a modern technological solution and complemented with perspectives from the community to provide new ideas for local development. The identification and naming of flora and fauna and local legends about different species and their relationships are all part of previous generations' narratives and can be a significant source of constructive conversation and meaningful answers to local concerns. The soil types found in their territories, for example, will be crucial in deciding the agriculture and varieties of planting to be established, as well as enabling for activities such as pottery, vegetable fiber work, and others, depending on the species found in their territories. This topic also gives space for discussing the importance of biodiversity or understanding the complexity of the ecosystemic balances.

5. Worldviews and spatial-temporal notions:

There are specific ways of measuring and interpreting time to guide domestic work, ceremonies, and other locally-relevant activities. Learning about ancestral calendars and symbolic representations of time are also fundamental aspects to connect and understand the local environment and social characteristics around the educational facilities. These structures are designed to track how much time one spends doing or should spend doing specific activities. Knowing some natural cycles, for example, can help determine the best times of day to do particular agricultural or other traditional activities. In addition, local knowledge about space, the stars, and other signs, that may be related to weather and other social and environmental phenomena is a highly appreciated local knowledge that can inspire motivating STEM4S projects. Furthermore, local worldviews, myths, tales, and oral traditions also reveal the value system of the previous generations, giving sight to the ethical and aesthetic perspectives grounded in the schools' contexts that can contribute to the debate about sustainability. Value-based discussion can help to create a climate of open dialogue and understanding of the moral dilemmas present in the complex sustainability problems that schools face in their surroundings.

Although the five domains presented here seek to connect local knowledge in indigenous contexts with STEM knowledge and skills, it is worth noting that local knowledge should not be trivialized or reduced to scientific thought codes. The inclusion of these topics, on the other hand, creates a place for discourse on historical and cultural issues, which, despite not directly agreeing with the scientific perspective, allows official learning opportunities to be placed in dialogue with other worldviews.

This analytic exercise does not intend universality in terms of covering all possible connections with local knowledge in Mapuche contexts. It is just a way to open the debate about the significant number of possible connections that can be proposed with an integrated and transdisciplinary scope, to open the schools to their territories, complexity, and main problems. It also opens the door to educational practitioners to find routes to transform educational opportunities, generating a real connection of the curriculum with their contexts and creating a space to build small solutions and make contributions to solve actual local and global challenges.

It is important to remark that this is not by any chance an attempt for a comprehensive understanding of the Mapuche perspective. Any attempt will end with a reductionist vision of the great diversity present in the Mapuche community. Instead, this analytical exercise tries to overcome the common essentialisms and provides opportunities to create constructive dialogues to affront real socioecological challenges. The Mapuche context is just an example that can be extrapolated to other indigenous and non-indigenous territories, like schools with high immigration populations willing to work in connection with their communities.

VI. DISCUSSION

The framework presented above condenses empirical work and educational efforts to change the way sciences have been traditionally taught in Chile. The effort made here has resonated in other Latin American countries and gained the academic community's attention in other world regions for its global and current relevance. That can be expressed in all the articles, book chapters, seminars, conferences, and congresses where this work has been shared (Bascopé, Caviedes, et al., 2021; Bascopé et al., 2019, 2020; Bascopé et al., 2021; Bascopé & Caniguan, 2016; Bascopé & Reiss, 2021; Pahnke et al., 2019).

This framework gathers the Latin American pedagogical tradition and connects it with the STEM concepts and international ideas about education for sustainability, theories linked with the North American and European pedagogical traditions. Freirean theories about popular education, education as a tool for freedom, empowerment, and emancipation provide the basis for a fruitful dialogue among these pedagogical traditions. These frames pursue the connection with local sources of knowledge to establish a horizontal dialogue and provide essential alphabetization tools to guide the new generations to read the world autonomously and help them to write a new path (Freire, 1978; Leff, 2002). Under this framework, critical pedagogy stands side by side with international frameworks that have been historically associated with standardized testing or top-down policy strategies, such as the UN or the OECD (OECD, 2018b, 2018a; UNICEF, 2016). This historical moment leads to an opportunity for radical change in the way things have been taught and learned, and this framework aims to contribute in that direction.

The presented framework attempts to contribute to science education for its inductive and practical focus, based on relevant challenges closely connected with the local community and with an integrated scope. It also has epistemological importance since it challenges the way we think about knowledge in school, taking the epistemological discussion to the classroom and allowing teachers and students to build a new and locally valuable knowledge. Besides, when applied to sustainability challenges in Latin American contexts, the relatively new trend of STEM education opens an ample opportunity to re-think and provide innovative and more inclusive learning opportunities for all (Bascopé et al., 2020). It is expected that his conceptual framework can support and inspire further attempts to provide learning from and with the community members of the school surroundings in many other contexts where educational practitioners wish to affront their socioecological challenges.

Researching about the implementation of STEM4S projects revealed a change in students' and teachers' motivation, a strengthening in the relationship with the external community, and clear directions to conduct further STEM educational opportunities focusing on sustainable futures. It is important to remark on the importance of scientific reasoning and argumentation. The practical experience of inquiry-based science with an inductive scope to learn from and with the school surroundings creates spaces for dialogue and learning about sustainability challenges. It also brings children closer to sciences, understanding its nature, procedures, and how to take science into practice.

This dissertation is situated at the intersection of two emergent research fields in education; STEM education and place-based education for sustainability in indigenous contexts. It is an attempt to contribute to the connection of STEM topics with current global sustainability problems and the necessity to open a horizontal dialogue with new perspectives for the collective action towards global warming, conservation of biodiversity, loss of ancestral knowledge and wisdom, and the failure of the political and economic systems to provide equitable opportunities and accesses to basic needs. In addition, the importance of students' engagement and motivation to create an environment for the development of individual and collective agency is also relevant for the educational systems to provide a renewed sense of purpose to face the challenges of the XXI century.

This work also opens an agenda for further research, allowing the connection of its different aspects and conducting more evaluative research, when the conditions allow it, using the guidelines that have resulted from this research project, both in Latin America and worldwide. For example, how SRA specific skills effectively develop in students involved in STEM4S projects? How do sociocultural aspects mediate this effectiveness? Which stages of the STEM4S projects are more relevant to creating students' engagement and motivation? How can we measure the real impact of STEM4S projects in the local community? Which are the long-term effects of STEM4S projects on local development? These are just some examples of possible research questions for future educational research in the area.

The urgency for a pedagogical scope change and the need to diversify educational methods are accelerated by the planetary urgency we face. Conceptually we are reaching a state where views on education that seemed to be opposed are reaching common grounds. Open and creative minds are needed for this process to settle on time. The new generations deserve educational opportunities up to the level of the global sustainability challenge. The conceptual paths, theoretical arguments, policy guidelines, and concrete ways for a real action plan are over the table. We just need more hands to push the wheel and break the inertia.

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