THEMATIC CLUSTER: CITIZEN SCIENCE

The EXPLORA model of citizen science at schools: design and implementation in the intercultural south of Chile

Camilo Gouet Hiriarta,b, Daniela Salazar Rodríguezc, Wladimir Riquelme Maulénc, Alejandra Rojo Almarzaa and Daniel Opazo Bunsterb

aCentro UC de Desarrollo Local, Campus Villarrica, Pontificia Universidad Católica de Chile, Villarrica, Chile; bCentro Nacional de Inteligencia Artificial, CENIA, ANID Basal, Santiago, Chile; cFacultad de Arquitectura y Estudios Urbanos, Pontificia Universidad Católica de Chile, Santiago, Chile

ABSTRACT
Citizen science has grown as a promising way to promote scientific education and democracy. However, the realization of these goals has been hampered as most programs in educational and other settings have used top-down approaches (where scientists direct the whole research path). Here we present a school bottom-up initiative, where students’ interests are raised and collaborative projects are developed in academies formed by students, teachers and scientists. Projects addressing local territorial identities are especially motivated by the program. In this work, we explored: (i) diversity of interests, (ii) learning outcomes, and (iii) the scientific quality of the projects. In two years of implementation in the intercultural south of Chile, we have worked with 52 academies, in projects covering a variety of research topics, including some that seek to rescue Mapuche’s traditional knowledge. We have observed the promotion of scientific and socioemotional skills in students, and projects have been judged of high quality by independent panels of experts. These results support the feasibility of citizen science to promote learning and to foster links between school and scientific institutions towards a more democratic scientific development.

O modelo EXPLORA de ciência cidadã nas escolas: projeto e implementação no sul intercultural do Chile

RESUMO
A ciência cidadã representa um caminho promissor para promover a educação científica e a democracia. No entanto, atingir esses objetivos é dificultado quando as iniciativas usam abordagens de cima para baixo (onde os cientistas lideram o caminho da pesquisa), o que é comum em iniciativas de ciência cidadã em ambientes educacionais. Neste artigo apresentamos uma iniciativa de ciência cidadã escolar com uma abordagem “bottom-up,” onde os interesses dos alunos são centrais no desenvolvimento de projetos colaborativos em “academias” compostas por alunos,

KEYWORDS
Citizen science; participatory sciences; democratization of science; interculturality; student-driven research

PALAVRAS-CHAVE
Ciência cidadã; ciência participativa; democratização da ciência; interculturalidade; pesquisa dirigida pelo aluno

PALABRAS CLAVE
Ciencia ciudadana; Ciencia participativas; democratización de la ciencia; interculturalidad; investigación impulsada por los estudiantes.

CONTACT
Daniel Opazo Bunster daniel.opazo@uc.cl

© 2022 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
professores e cientistas. O programa promove especialmente projetos que abordam identidades territoriais locais. Neste artigo exploramos (i) a diversidade de interesses, (ii) os resultados da aprendizagem e (iii) a qualidade científica dos projetos. Em dois anos de implementação do programa em uma região intercultural no sul do Chile, trabalhamos com 52 academias, com projetos que abrangem diversos temas de pesquisa, inclusive alguns que resgatam o conhecimento tradicional Mapuche. Além disso, temos observado a promoção de competências científicas e socioemocionais nos alunos e a qualidade científica dos projetos tem sido bem avaliada por painéis independentes de especialistas. Estes resultados apoiam o valor da ciência cidadã para promover a aprendizagem transversal e gerar ligações entre a escola e as instituições científicas que fomentem um desenvolvimento científico mais democrático.

El modelo EXPLORA de ciencia ciudadana en las escuelas: diseño e implementación en el sur intercultural de Chile

RESUMEN
La ciencia ciudadana representa una forma prometedora de promover la educación científica y la democracia. Sin embargo, la consecución de estos objetivos se ve obstaculizada cuando las iniciativas utilizan enfoques “top-down” (donde los científicos dirigen la ruta de investigación), lo que es común en iniciativas de ciencia ciudadana en entornos educativos. En este artículo presentamos una iniciativa de ciencia ciudadana escolar con enfoque “bottom-up,” donde los intereses de los estudiantes son centrales en el desarrollo de proyectos colaborativos en “academias” formadas por estudiantes, docentes y científicos. El programa impulsa especialmente proyectos que aborden las identidades territoriales locales. En este trabajo exploramos (i) la diversidad de intereses, (ii) los resultados de aprendizaje y (iii) la calidad científica de los proyectos. En dos años de implementación del programa en una región intercultural del sur de Chile hemos trabajado con 52 academias, con proyectos que abarcan una variedad de temas de investigación, entre ellos algunos de rescate del saber tradicional Mapuche. Además, hemos observado la promoción de habilidades científicas y socioemocionales en estudiantes, y la calidad científica de los proyectos ha sido bien evaluada por paneles independientes de expertos. Estos resultados respaldan el valor de la ciencia ciudadana para promover aprendizajes transversales y generar vínculos entre instituciones escolares y científicas que fomenten un desarrollo científico más democrático.

1. Introduction

The field of citizen science has expanded rapidly in the past decade, inviting people from multiple backgrounds to participate in science. Due to this expansion, many initiatives have pushed projects in educational settings amid the promising value of citizen science (CS) to promote learning and more empowered citizens. Despite this wave of enthusiasm, calls have been made to improve CS experiences so they can effectively promote such outcomes, and to incorporate ways of measuring them before CS can fit in curricular activities to
promote scientific education. In this study, we aim to contribute with these ongoing efforts, by presenting a school CS program where students’ interests are raised and place-based research projects are developed collaboratively.

The importance of promoting scientific education has been acknowledged as contributing both to individual and societal developments from intellectual, ethical and economic points of view (Trott 2021; Zimmerman 2007). In developing regions such as Latin America, students tend to score well below those from developed countries in international tests of scientific competence (PISA 2015 Results, see Gurría 2018), diagnosing one of the many ways in which inequalities manifest globally. Multiple factors, including socioeconomic and migrant origin have been raised to explain this scenario (Gurría 2018). In recent years, initiatives within citizen science – where laypersons participate in some aspects of scientific research – have been put forward as vehicles to foster scientific education in schools and other settings. Although the idea of bringing “real” or hands-on scientific experiences to schools is not new in education (Claxton 1994), it has regained momentum due to the flexibility in content and format that CS projects can afford (Bautista-puig et al. 2019; Kullenberg and Kasperowski 2016) but also for the implications beyond learning that can be achieved. Indeed, as we will see, a distinctive value of citizen science over active learning and other successful constructivist interventions in education (Freeman et al. 2014) is that it can contribute to learning but also to form empowered citizens and ultimately to the democratization of science (Trott 2021). This view of CS, put forward by Irwin (1995) and Callon (1999) and that we fully endorse here, invites thinking of schools as playing a crucial role in the search for a more democratic, locally based, scientific and technological development. As we shall see, however, the realization of such potentialities (educational and democratic) has shown to depend among other things, on the degree of participation of laypersons in CS, which can vary considerably between programs.

In top-down projects, laypersons mostly contribute by collecting data and/or by performing some data analysis in projects already designed by scientists. This approach (also called participatory projects; Bonney et al. 2009; Shirk et al. 2012) has proven successful in fostering what is called the instrumental side of citizen science (where people work as “instruments” to contribute in achieving difficult scientific tasks). Beyond providing concrete experiences for laypersons to contribute with data while also learning about procedures and concepts in science, in educational settings this approach has brought the benefit of clearly delimiting the goals of a project and providing ready-to-use material for students (Kloetzer et al. 2021). However, despite all these benefits, top-down designs have shown to carry some drawbacks. For example, in the project “Cell Spotting” by Silva et al. (2016), school students classified images of cells treated with anticancer drugs. Students reported that the idea of contributing to an important project of anticancer therapies was motivating and some of them reported to have learned about cellular biology and how scientists work. However, curiosity was not engaged and the confidence in making a significant contribution to the project was judged relatively low. Similarly, Perelló et al. (2017) found that some scientific competencies and motivation were less promoted in guided inquiry (top-down) projects than in open inquiry projects (where students played a central role in defining the research questions). In addition, top-down approaches can also be blind to student and communities’ interests because scientific agendas do not typically match communities’ interests and concerns. This can affect the commitment to
participate in a program and the empowerment of students, weakening the democratizing role of citizen science and compromising the long-term sustainability of the projects. On the other hand, several authors have highlighted the importance of recognizing children as “human beings” rather than “human becomings,” advocating the need for an urgent cultural change, where adults take seriously the perspectives and experiences of the youth to encourage their informed and active participation in their lives (Qvortrup 1985; Sanson, Van Hoorn, and Burke 2019; Vaghri 2018; Trott 2021).

Sociological and historical analyses suggest that such meaningful, active participation of students can be best accomplished using bottom-up designs (Callon, Lascoumes, and Barthe 2009; Gray, Nicosia, and Jordan 2012; Mueller, Tippins, and Bryan 2012), also named co-design projects (Bonney et al. 2009). Analogous to the “hybrid models” in the literature of Science, Technology and Society (STS) studies (Callon 1999), the core ingredient here is the suspension of the vertical, asymmetric relationship between experts and layperson that typically characterizes top-down projects, for one where each group of participants brings knowledge and skills for the realization of a project. As a consequence, laypersons end up not just passively receiving knowledge from an outside world of experts but can actively participate in its generation, motivated by problems of their own concern. This approach has been mainly adopted in cases where communities have requested scientific expertise to solve a problem, or a legal dispute has brought together communities, scientists, and mediators to search for solutions of socio-technical issues (see a recount of experiences in Callon, Lascoumes, and Barthe 2009 and Invernizzi 2020). The benefits of this dialogic approach where science and society come closer can be immense, unforeseen, and expected at both sides, as the former can become aware of issues and knowledges previously unnoticed in mainstream lines, while the latter can profit from the expertise grown in scientific realms, triggering successive cycles of elucidation (Callon, Lascoumes, and Barthe 2009).

In spite of their potentialities, bottom-up designs have been relatively underexplored in educational settings (e.g. Perelló et al. 2017; Ruiz-Mallén et al. 2016. See review in Kloetzer et al. 2021). A remarkable case is the one of Mrs Bingaman and her students. As described in Schon et al. (2014), worried about the contamination of a creek that passed next to their school backyard, this teacher and her fifth-grade students set up a project to monitor the quality of the water. As time passed, the project grew and students started also monitoring the health of fish and invited scientists to join the group. In the end, students became so empowered that they raised funds, brought together landowners and authorities, and ended up producing policy changes. These results indicate that by raising students’ interests, scientific and other institutions can become aware of meaningful problems for communities, enhancing the democratic role of CS. At pedagogical and cognitive levels, giving students the freedom to explore the environment can foster their curiosity, a driving force for scientific inquiry and learning (Engel 2011; but see Kirschner and Clark 2006) and offers a constructive-pedagogic perspective, where teaching is not merely transferring knowledge, but creating the possibilities for its own production or construction (Freire 1999).

In this study, we seek to contribute with CS from the bottom-up side, presenting the EXPLORA program of school citizen science and describing the results of two years of implementation in southern Chile (2019 and 2020). EXPLORA is a Chilean, countrywide governmental initiative born in 1995 to promote and socialize scientific knowledge and innovation in the community. It encompasses multiple programs and activities, following
a constructivist perspective on education (Díaz-Barriga and Hernández 2002). It fosters meaningful learning experiences (Ausubel 1983) and emphasizes scientific promotion with local needs.

During our CS program, primary to high school students proposed their own research ideas and worked vis-a-vis with teachers and scientists to develop them. The formed “academies” worked for one semester. To get the most out of the bottom-up design, we implemented the program in the south of Chile (Araucanía Region), which belongs to the Wallmapu territory, the ancient land of Mapuche people. This is an intercultural territory with rich cultural and natural diversity. On the natural side, different landscapes include alto andean lakes, rivers, active volcanoes and old forests of millenary trees such as the Monkey puzzle tree (*Araucaria araucana*, which gives the name to the region). Valleys and terrains for agriculture are also found, all flanked by the Andes mountains to the east and to the Pacific coast to the west (Figure 1). On the cultural side, this is an intercultural territory, due to a historical and ancestral presence of Mapuche people, who have lived together with Chileans and people from other nations since the middle of the 19th century.

Different investigations have highlighted that intercultural contexts allow diving into the processes, relations, and interactions that recognize ancestral wisdoms through the attentive listening (“escucha atenta”) and respect to those who possess those wisdoms (Quilaqueo and Quintriqueo 2017; Payàs and Le Bonniec 2020). For the Mapuche (which in their language, the mapudungun, means people of the land: “mapu,” people; “che,” land), the wisdom of their ancestors is the first source of communicative education, whose knowledge links nature with the everyday (Durán 1995). The understanding of educational processes in intercultural settings has been framed as the construction of a “double rationality,” implicit in the Mapuche people: it is revealed in their daily duties and combines elements from the Chilean culture, their own families, and ancestral wisdoms (Quilaqueo et al. 2014; Quilaqueo, Fernández, and Quintriqueo 2020).
As shown in Figure 1, academies were held in rural and urban schools covering the main parts of the region. Unfortunately, the rich cultural and natural diversity of this region is overshadowed by the highest poverty levels of the country (data from the socio-economic characterization survey CASEN, 2020). This unfortunate situation, however, further motivated our program. Active learning experiences have proven especially effective for minorities and underrepresented groups (Freeman et al. 2014; Theobald et al. 2020), and citizen science can also help to cope with this situation (see Peltola and Arpin 2018). It is important to note that for the present work, we conceived the inter-cultural context as an opportunity to leverage the potentialities of bottom-up designs, mainly to expose interests and local concerns that could be highly diverse in these contexts. In Brazil, for instance, where there is a high presence of indigenous people, initiatives from CS have been developed, addressing issues related to climate change and environmental transformations (Albagli and Iwama 2022; Clinio 2019; Iwama et al. 2021). Raising the research topics in school communities and elaborating them throughout the program is a relevant step that can subsequently inform the scientific community and, eventually, political authorities of interests that could be invisible otherwise. They can also diagnose beautiful expressions of syncretism between cultures as we will see.

Thus we set up three main goals: first, to organize and expose the diversity of research interests shown by students. Due to the openness of the design implemented and the heterogeneous territorial context, we expected diversity to be high. Second, to identify potential learning outcomes, including scientific competencies and socioemotional skills. Measuring learning outcomes is important to compare programs on empirical grounds to determine the educational value of CS, and many research groups have pointed to an important gap in the literature in this respect (for an overview, see Kloetzer et al. 2021). Following recent recommendations (Bela et al. 2016) and similar projects to ours (e.g. Perelló et al. 2017), we combined qualitative and quantitative tools. Although we did not have specific expectations in this regard, based on the results of top-down experiences, we expected our program to contrast with them and to engage motivational aspects and scientific skills linked to finding questions and inquiry.

Finally, in our third goal, we assessed the scientific quality of the investigations. Determining scientific quality has been a concern surrounding citizen science, which has lowered thanks to the ample evidence of high-quality works produced (Bonney et al. 2014). In educational settings, encouraging results have been shown in the form of peer-review publications carried out by students (Andújar et al. 2015). Note that quality measures do not only signal learning on the part of students but also help diagnose the capacity of a program to foster productive collaborations between schools and scientific institutions that can sustain long-term collaborations. Scores obtained by the academies in a regional congress of science were used as measures of scientific quality.

One last note on implementation. The second year of implementation was 2020, the year of the COVID pandemic. We introduced a series of adaptations to cope with this
situation as in recent educational experiences in Chile (Piñones-Cañete, Pastén-Tricallotis, and Jopia-Quinones 2021; Silva-alé 2021). This information can be an input to future CS programs in which virtual and in-person activities are combined. Overall we expect our results can contribute to support student-driven research initiatives.

2. Methods

In this study, we present the EXPLORA program of citizen science implemented in 2019 and 2020. The overall organization was similar in both years, but due to the pandemic in 2020, we performed some activities remotely, as indicated below.

2.1. Participants

In total, 405 students, 51 teachers, and 47 scientific advisors participated in both years. In 2019, we had 308 students (153 females, from fifth to twelfth grade of high school), 32 teachers, and 28 scientists. In 2020, we had 97 students (43 females, from first to twelfth grade of high school), 18 teachers and 18 scientists.

Children came from 41 schools located in 21 districts of the region (some schools participated in both years and some held two academies in the same year; further sociodemographic information is presented in Section 3). Scientific advisors came from six universities of the region: Pontificia Universidad Católica, Universidad Santo Tomás, Universidad Autónoma, Universidad de la Frontera, Universidad Católica de Temuco, and Universidad Mayor. One advisor was associated with the University of Barcelona and one with CONAF (a private-public institution in charge of national parks). One advisor was an independent professional.

Students and parents/caregivers gave written assent and consent, respectively, before participating in the program. The participation in the program was voluntary for all members of academies (students, teachers, and scientists) and no economic incentives were given to the teachers or scientists.

2.2. Academies’ structure

In total, we gathered 52 academies, 32 in 2019 and 20 during 2020. The number of students within academies ranged from 2 to 15 (mean = 7.8 students per academy). In each academy, students belonged to the same class level (with few exceptions where students came from two contiguous levels). Each academy had one teacher and one scientific advisor. One scientific advisor participated in three academies in the same year. Three academies did not have a scientific advisor.

During the program, academies reached different levels of completeness. Of the 52 academies, 34 completed the entire program; 15 reached an intermediate level (they proposed a project and executed it until obtaining some results); 3 reached a beginning level (they proposed a project but did not implement it). The reasons for withdrawal were mainly due to problems derived from the political strikes in Chile at the end of 2019 and from the pandemic in 2020. We kept the entire sample of academies regardless of their level of completeness because valuable information for the assessment of the program and our goals could still be obtained (for instance, sociodemographic aspects, topics of interests,
among others presented below). For the analyses regarding scientific skills and products, we included only academies that completed the entire program (see below).

### 2.3. Design

The design of the program is shown in Figure 2. In the call, projects aimed at producing basic research or innovations were invited to participate in one or more of the following fields: Natural, Medical, Agricultural, and Social Sciences; Engineering and Technology; and Humanities. In addition, projects promoting gender equality, and territorial and social relevance were especially encouraged in the call. In 2020, an explicit motivation to propose interdisciplinary projects was included in the call, and research projects in the arts were also allowed to apply. Also due to the pandemic, in this year projects had to be non-experimental ones.

After the call, enrolled academies received scientific advice in three main stages of the research path: elaboration of the research question (workshop 1); methodology (workshop 2), and data analysis (workshop 3). These were conducted by the EXPLORA team and/or by scientific advisors. W1 gave advice on focalizing and framing the research questions and/or hypothesis formulation. In 2020 we included advice in performing non-experimental research, along with methods training for teachers before academies began. Technical support for teachers can contribute to the success of CS projects in schools (Kloetzer et al. 2021). At the end of the program, students presented their projects in outreach activities: a regional congress of school science in 2019 and 3–5 min videos in 2020. The whole program lasted 6 months.

---

**Figure 2.** EXPLORA citizen science program design. Upper panel, main steps during the program. Scientific advice is provided in workshops to support different stages of the research process, followed by periods of actual research conducted by academies. At the end of the program academies present their results in outreach activities. The lower panel shows the evolution of a territorial network that builds up as the program unfolds.
2.4. Implementation

The open call was released through EXPLORA’s social media; teachers and scientists were invited by email using regional databases. In the first year (2019), scientific academies developed their projects in the schools. Teachers were requested to dedicate at least 2 academic hours per week during school time (some academies also worked during after school time, and others were motivated enough to continue working during weekends). Workshops 1 and 2 were carried out in-person, in two cities of the region (Temuco and Victoria), gathering all students and teachers from all the academies. They were carried out by the EXPLORA team. Scientific advisors participated in two instances, one corresponding to Workshop 2, in which they were introduced to the academies and gave methodological advice to the groups. The second was Workshop 3 and was held remotely, giving data analysis/discussion advice to the groups. In 2020, workshops and research investigations followed the same structure and were carried out remotely (using platforms such as Zoom or Google meet). In addition to these predefined activities, academies could contact the EXPLORA team and the scientific advisors at any moment to request further advice. The EXPLORA team also kept continuous monitoring of academies throughout the program.

2.5. Instruments

2.5.1. Process log and rubric

To identify the scientific skills promoted in the program, teachers were requested to fill in a process log during the execution of the program. The process log contained a series of questions indexing the skills of a research path:

1. Act with curiosity
2. Search for opportunities of inquiry
3. Discovery of alternative solutions
4. Project design
5. Project execution
6. Data analysis
7. Communication

These skills were defined as follows:

1. **Curiosity:** The capacity to confront new situations with a disposition to observe and ask, showing a capacity of inquiry and accepting moments of confusion that may appear.
2. **Inquiry:** The capacity to select problematic situations, recognizing their elements, the relation between them and the potential causes involved to reach a precise formulation of the problem to be investigated.
3. **Alternative solutions:** The capacity to propose the research alternative that will be contrasted during the investigation, being the most viable, relevant and consistent according to the problem to be investigated, and that allows tight control of the variables involved.
4. **Project formulation**: the capacity to plan a research of any kind, considering the strategy, workplan, and the necessary proceedings that may support the proposed explanation.

5. **Project execution**: the capacity to carry out the actual research according to the work plan, using available technology, tools and knowledge, thus providing information to the explanation of the problem under study.

6. **Data analysis**: the capacity to think critically about the results, the investigation, the information, and the implications of the work done for daily life.

7. **Communication**: the capacity to use the language typically used in the research field under study to communicate the work in a precise, comprehensive, opportune and efficient manner.

We then applied a rubric to the process logs using a three-point scale (with 0, not-accomplished; 1, accomplished, and 2 well-accomplished) (see also Perelló et al. 2017). For academies held in 2019, we did not obtain a measure of Curiosity. For Data Analysis, we used two indexes that were averaged in a single measure.

### 2.5.2. Focus groups

To complement the rubric (which provides a measure at the group level of academies), we performed a series of focus groups with students, teachers, and scientific advisors to inquire about participants’ experiences (see Vitone et al. (2016) for a similar combination of quantitative/qualitative methods). The interviews covered multiple topics, among them: the application to the program, expectations to participate, perceived learned skills, human relationships, the value of the scientific advice, relation to the territories, etc. In this study, we focused on two topics: students’ learning experiences (i.e. what students, teachers, and scientists perceived about learning in the program), and human relationships. The focus groups were conducted with academies held in 2020.

### 2.5.3. Scientific quality of the projects

At the end of the program, academies presented their projects at a regional congress of school research. A jury of independent researchers (not involved in the EXPLORA team) evaluated stand presentations and written documents presented by each academy. Here we used the stand evaluations as a measure of quality because these covered more criteria of interest than the written evaluations. The quality criteria were:

- Clarity and rigor
- Involvement
- Creativity, originality, innovation, and impact
- Critical thinking
- Communication
- Territorial relevance

The criteria “Involvement” and “Territorial relevance” may not be familiar to the readers. The former measures the confidence and degree of command of the topic investigated, and to what extent students were actively involved in the project. Territorial relevance measures whether the project includes environmental, social, cultural and/or
economic elements in the research question; whether it uses methods and techniques that consider these elements or whether it links with other social actors that belong to the local community.

We obtained these evaluations for academies held in 2019. The congress did not take place in 2020 and academies presented their investigations as audiovisual material.  

2.6. Data analysis

Scores from rubrics and quality criteria were summarized using means and standard deviations. Although means can be used in ordinal scales provided their meanings are interpreted with caution, we also present frequency distribution of responses as suggested by Sullivan and Artino (2013) (see Supplemental Material Figures S2 and S3). Statistical analyses included repeated ANOVA measures (when aggregating data across academies), and MANOVA (using Pillai’s trace statistics) when separating by some dimension (rural versus urban school, year of implementation, financial support of school, etc.). Post-hoc comparisons were done using t-test corrected for multiple comparisons (Bonferroni correction) and using Games-Howell post hoc test for the MANOVAs. These were implemented using the package rstatix in R (R Development Core Team 2017). Criteria of significance were p < 0.05. Focus groups were transcribed and content analysis was performed by an external expert.

3. Results

3.1. Academies in the territory

EXPLORA academies were held in La Araucanía region, which belongs to the Wallmapu territory, the ancient land of Mapuche people (Figure 1). The 41 schools covered more than 60% of regional districts indicating good territorial representativeness. Sociodemographic indicators showed that 76% (31/41) were urban schools and 24% (10/41) were rural schools. At the regional level, the proportion of rural schools is higher (58%), suggesting that they were under-represented in our study. Roughly half of the schools were public (21/41), and half were privately subsidized (private institutions that receive government support) (19/41); only one academy was held in a private school. These proportions roughly match those seen at a regional level. On the other hand, consistent with the high levels of poverty of this region, 94% of the academies came from schools with high vulnerability risk indexes.

3.2. Academies in action

The bottom-up design of the program sparked students’ motivation to search for questions relevant for them and their communities (see Figure 3). Thus, one of our goals was to expose and organize such interests according to different criteria. First, we classified the projects according to their focus (i.e. innovation or investigation) and field of science, separating by year (Figure 4(A)). In both years, we observed more

---

2See www.youtube.com/playlist?list=PLJrxvUrl7CtB386rUz5hm66M80NI.
research-oriented projects than innovations (accounting for 66% in 2019 [21 out of 32] and 80% in 2020 [16 out of 20]).

Regarding research fields, we found that projects within the Natural Sciences and Engineering and Technology prevailed in 2019 (representing 34% and 25%, respectively)
and dropped considerably during 2020 (20% and 10%, respectively). Notably, projects in Social Sciences instead raised from 13% in 2019 to 35% in 2020, surpassing the other fields. Finally, projects in Agricultural Sciences dropped from 13% in 2019 to 5% in 2020, while those in Medical and Health Sciences raised from 15% in 2019 to 30% in 2020. Although these differences should be considered with caution as the number of projects was different in both years (32 in 2019 and 20 in 2020), this reorganization, particularly the rise of Social Sciences could be due to the fact that in 2020 we called for non-experimental projects, in which Social Sciences have more associated sub-disciplines.

Next, we inspected the degree of interdisciplinarity of the projects (i.e. whether they combined two or more research areas) and found that the proportion of unidisciplinary and interdisciplinary projects was similar across years (Figure 4).

To further inspect the topics and better expose their diversity, we categorized them according to subfields of science (Figure 4). We can see that the variety is huge. Interestingly, among all the projects, 12 investigated some aspects of the Mapuche culture, consistent with the program’s aim to promote research with territorial significance. These specific projects covered the medicinal use of plants, the perception of natural phenomena (e.g. a solar eclipse, contamination of rivers) from the Mapuche cosmovision and how to rescue ancestral traditions of breeding plants. One project used digital sculpting techniques to model traditional objects and shared them in a public exhibition, combining traditional knowledge with computational tools. Another one even used a mixture of research methodologies, taking the data based on nütram – a space for a deep conversation and learning of the Mapuche culture. Furthermore, we observed a broad concern in academies about environmental issues (9 projects), mainly to identify causes/consequences of water resource contamination. We also observed projects in the social sciences investigating socioemotional effects of the isolation in pandemic, and other topics related to public health. Together, all these themes reflect the wide variety of interests students have in their surroundings that they bring to the program.

### 3.3. Learning outcomes

Besides exhibiting the diversity of research interests, we aimed to identify scientific skills that may have been promoted in the program. We used a process log that teachers filled in at the end of the program and applied a three-point scale rubric to the logs (with 0 = not-accomplished; 1 = accomplished; 2 = well-accomplished). After a first analysis in which we aggregated all academies to inspect global trends (Supplemental Material Figures S1 and S2), we separated academies by type of school (rural versus urban) to evaluate potential differences in this dimension. As shown in Figure 5, we found that, in general, academies reached above-accomplished levels across all scientific competencies. In rural schools, the dimensions of curiosity and communication pointed highest (curiosity: $M = 2$, $SD = 0$, $n = 4$; communication: $M = 1.89$, $SD = 0.33$, $n = 9$) and project execution was the lowest ($M = 1.33$, $SD = 0.87$, $n = 9$). Urban schools seem to show a less variable pattern than rural schools, though communication was higher than the other skills ($M = 1.86$, $SD = 0.53$, $n = 14$). Although these results can suggest some differences in the outcomes between academies depending on the type of schools, they were not statistically significant ($F_{(6,11)} = 1.0817$, $p = 0.429$) (see also Supplemental Material Figure S3). In further analyses, we inspected potential differences between
outcomes linked to the financial support of schools (Supplemental Material Figure S4) and the year of implementation (Supplemental Material Figure S5) and again found no significant differences, suggesting that the program was equally effective in promoting scientific competencies regardless of the conditions of schools.

The results above concerned group level units, i.e. academies. To evaluate whether the program also promoted scientific skills at the level of participants, we performed a series of focus groups with teachers, students, and scientists (n = 4 for each of them, academies held in 2020; see Section 2). For the present study, we focused on what teachers and scientists perceived about student’s learning, and what students themselves reflected about their own learning.

### 3.3.1. Teacher’s voices

Consistent with the process log results, teachers’ testimonies highlighted that students acted with curiosity, and that the program was very engaging for students because the questions came from them. In addition, teachers asserted that some students learned about the existence of Social Sciences and realized that they could do science by investigating people’s experiences and “simple” things of their surroundings. Likewise, students learned to identify a research question, to work in groups and with rigor, and exercised communicative skills:

![Figure 5. Scientific competencies evaluated in the program divided by type of school. The bars depict average scores from the rubric applied to the process log. The blue dotted line indicates the “accomplished” level (score 1 on the rubric’s scale) (the other two levels were 0 = not-accomplished and 2 = well-accomplished). Error bars show the standard error of the mean (SEM).](image-url)
[students learned the value] of communicating through audiovisual media and make the communication of a scientific finding something appealing, funny, engaging, that can sensitize people. (A teacher’s testimony, Focus Doc, page 7)

These results are in line with those shown for the process log above (with curiosity and communication skills showing the highest punctuations). Besides the scientific skills, teachers also noted that students became empowered and self-confident, which helped them to pursue their projects to the end. They also became aware of ethical issues when conducting research, helping them to adhere to scientific protocols, but also to reflect on the impact that doing science may have on social and natural environments.

3.3.2. Scientists’ voices
Scientists said that students mainly learned methodology during the program. Specifically, to sharpen their research questions and propose something realistic to be achieved given the resources and time constraints. They also pointed out that students learned to search for useful bibliography using platforms such as Google scholar (which students noted was useful for other classes beyond sciences) and that there are investigations that do not require experiments:

[students could] see other possibilities to do research, of not just doing laboratory research, things like that, but to be able … of looking at biological process from a more social perspective. (A scientist testimony, page 22 Focus Doc)

Scientists also noted that students and teachers alike reflected on the value of traditional knowledge and the importance of keeping it alive, and the impact that research may have on the community as a whole:

I feel this was my major influence in methodological terms of what they were doing, and furthermore, it is shown in the reflections that the teacher raises in the final video, in that we can think of medicine from the perspective of local wisdom. (A scientist testimony, page 23, Focus Doc)

3.3.3. Student’s voices
Among the skills identified, students highlighted to have exercised the capacity to act with curiosity (in line with teachers’ testimonies above). They pointed to the importance of this skill to find a research topic, value the obtained results, and generate further research questions:

For me it is interesting this “acting with curiosity,” because curiosity brings me to the interest about our topic and to analyze the results that brought us to know and value a remarkable fruit (that they investigated about) … This leads us with an interest in continuing with our study, above all, with this project. (Student testimony, page 17 Focus Doc)

In addition, in line with scientists testimonies, students acknowledged to have learned methodological tools, in particular, to frame a scientific question, search for relevant bibliography, and plan and carry out a project:

I think what I learned the most was to differentiate between different sources of information and to find good sources about the topic I want to investigate. I learned this well, in a good
manner, I mean in the academy and I think it will help me a lot in the future. (Student testimony, page 16 Focus Doc)

In this context, the advice of the scientific advisor was very important:

[he/she] helped us a lot in the research topic and taught us, it helped us a lot by telling us in which web page to search and how to do it, it taught us many things that helped us in answering our research questions. (Student testimony, Focud Doc, page 16)

Taken together, the results of the logs and focus groups suggest that students exercised scientific skills, especially curiosity, methodology (search for information and focalization to frame research questions), and communication. Socioemotional skills and reflection capacities were also engaged during the program.

### 3.4. Scientific quality of the projects

At the end of the program, academies presented their projects in outreach activities: a regional congress of school science in 2019 and with audio-visual material shared on YouTube in 2020. To assess the quality of the projects, we focus on congress presentations because they were evaluated by a board of external scientists (not involved in our program), offering an independent measure of quality. Figure 6 shows a sample of congress presentations and depicts the results obtained in scientific evaluation. For most criteria, we observed that EXPLORA academies \((n=19, \text{each project evaluated by two scientists})\) obtained on average more than 4 points from a maximum of 5, suggesting that the projects were judged of high quality (see Section 2 for details of evaluation criteria). Involvement (i.e. the degree of engagement and commands of the topics during stand presentation) and Local Relevance were the highest (respectively with \(M=4.37, SD=0.13\) and \(M=4.3, SD=0.91\)) and Critical thinking was evaluated lowest (\(M=3.77, SD=0.875\)). An ANOVA with repeated measures yielded an overall significant difference between criteria \(F(5,185)=6.97, p<.001\). Post-hoc comparisons showed that “Involvement” was significantly higher than “Clarity & Rigor,” and that “Critical Thinking” was significantly lower than “Involvement,” “Creativity & Originality,” “Communication” and “Local relevance.”

During the congress, other school academies participated along with EXPLORA’s. This allowed us to evaluate the relative performance of our program. We had no specific expectations for this comparison regarding quality criteria except for the dimension “Territorial relevance.” This is more explicitly emphasized in our program compared to other programs (see Section 2) and so we expected to find higher scores in this criteria. In general, we found that EXPLORA academies outperformed other academies \((n=9)\) in all criteria (Figure 6). Statistical tests yielded a main effect of group (EXPLORA vs Others) \(F(6,49)=2.41, p=0.041\) and post-hoc comparisons showed that Local relevance was significantly higher in EXPLORA than in the other academies, in line with our expectations. No other differences were significant. However, these results must be analyzed with caution because we did not have detailed information on the characteristics of the other research groups, and this comparison was not the main focus of our present work. Overall, these results reinforce the promising value of school research for producing scientific pieces (either from our program or others) with local relevance to the territories.
3.5. Building communities of school research

In the last section, we explored to what extent our program is helping to build real communities of school research, as these are the building blocks of any enduring impact our program may have in the future. We distinguished two levels of community relationships, one involving persons (students, teachers, and scientists) and another involving institutions (schools and universities/research institutions).

3.5.1. Human community level

In the same focus groups described above, we also inquire about relational and socio-emotional aspects. Figure 7 schematizes a summary of the main findings.

3.5.1.1. Teachers–students link. The relationship between teachers and students became more horizontal and closer during the program. Teachers said that they were open to talk about scientific but also more personal things, with trust and confidence. Interestingly, this environment let them appreciate in their students other abilities that were relevant for the success of the academies, other than cognitive abilities, namely determination, the capacity to work in teams, and self-efficacy. Students also experienced similar feelings:
It was not the same as being in classes, [here] the teacher guided me, but it was also a research partner. (Student testimony, Focus DOC, page 15)

3.5.1.2. Scientists–students link. For some scientists, establishing productive and closer relationships with students was challenging, mainly because of the lack of curricular aspects and because students were unaware of some ethical procedures when doing research. In other cases, the relationships were closer and more easily established. Overall, scientists valued the program and the possibility of knowing more about students and their interests:

And this academy, beyond formal academic aspects, gives you contact with adolescents, who have dreams, who have a life project, that are building it and it is also a ground cable for me in terms of what are those dreams, what expectations do they have. (Scientist’s testimony, Focus Doc, page 24)

From the students’ perspective, we found that they valued the possibility of knowing more about how scientists work, and to receive first hand methodological advice. Some students even reported that their scientific advisor played a motivational role:

[He/she] taught us, clarifying things and doubts we had, and it was like, well, first it was like funny, we talked about us, but we knew each other. Then it started guiding us and motivating us with the project and to keep investigating. (Student testimony, Focus Doc, page 24)

3.5.1.3. Teachers–scientists link. Scientists were perceived as “knowers” of their fields by teachers, and that can provide useful methodological advice. However, some teachers pointed out that in some cases, the relationship between students and scientists was too strictly academic, leaving aside more affective or “familiar” aspects that are relevant for students. Regardless, the overall impression is that the link with scientists was fruitful and positive.

Figure 7. Building communities with people and institutions. Left, schematics with summary statements indicating how students, teachers and scientists perceived each other and their relationships (see main text for details). Right, institutional networks linking school and universities (Right image obtained using the package Leaflet in R).
He kept permanent contact through email, checking our progress even before we sent any document. He checked everything, always giving feedback. And the truth is that it was wonderful, the last meeting we had, …, because he gave beautiful words for students’ efforts. Indeed, he asked to receive the video we produced. … So this year the scientific advisor was top. (Teacher testimony, Focus Doc, page 9)

Conversely, scientists noted that teachers (and students) were motivated to learn methodological tools. More generally, scientists valued participating in the program as an opportunity to be aware of the issues of interest to students and teachers and highlighted that academia should, in general, be more aware of territorial problems to produce knowledge.

3.5.2. Communities at institutional level
At the institutional level, we ended up connecting universities with many schools of the region (Figure 7). Even though the universities were located in two cities of the region (Temuco and Villarrica), they linked with more than 60% of the districts of the entire region, revealing a high capacity of our citizen science program to bring together multiple actors to address meaningful issues for communities.

4. Discussion
A major challenge for developing societies is to devise effective and engaging educational programs to promote scientific education. This goal will not be fully accomplished if we do not pay close attention to what students care about in this world. Over recent decades, citizen science has stood out as a promising avenue to foster education and democracy together. In this work, we set three goals: to test the capability of bottom-up designs for exposing the diversity of interests, to measure learning outcomes, and to evaluate the scientific quality of the projects. For each of these goals, we found positive results after two years of implementation in the intercultural south of Chile: we uncovered many interests in our students, measured engagements of scientific and socio-emotional skills, and projects were generally evaluated as having good quality. These results support the feasibility of including CS in schools to promote learning through place-based collaborative research between scientific and school communities. Our model can also foster democracy, binding science with local public policies, since it allows identifying and investigating socio-environmental topics, promoting possible solutions and actions to address them.

4.1. Exposing diversity
One of the signatures of bottom-up designs is that they can function as “screeners” of diversity, helping to lift information about people’s interests and concerns in a given territory. Our first goal was to test this capability and got impressed by the wide diversity of themes students came up with, with projects in environmental, energetic, and health issues among many others. This design approach gave us not only a global picture of interests but also how these can adapt to large changes in context, such as the one imposed by the pandemic. But perhaps the most significant value of the openness of the bottom-up approach resulted in its implementation in the intercultural south of
Chile. A number of academies were motivated to rescue traditions and knowledge of their Mapuche ancestors, in projects related with medicine and cosmovision of astronomical events (the eclipse). Others attempted to mix traditional knowledge with modern tools, for example, by creating a virtual exhibition of Mapuche’s artwork, or by incorporating the nütran (the attentive and deep conversation of the Mapuche knowledge) into a social science project. These creations can be seen as manifestations of the “double rationality” implicit in Mapuche people’s education as inhabitants of an intercultural territory, where foreign cultural practices (Chilean) are combined with knowledge of their families and ancestral wisdom (Quilaqueo et al. 2014; Quilaqueo, Fernández, and Quintriqueo 2020).

The capacity of a program to expose diversity is an important asset. Indeed, historical accounts have documented the hard and sometimes painful processes underrepresented groups need to experience on the road to be visible to other members of society (Callon, Lascoumes, and Barthe 2009; Invernizzi 2020). The conditions needed for and the mechanisms through which groups conform their identities and goals vary substantially between contexts (for example, parents whose children are affected by an otherwise unnoticed illness or people living nearby a sacrifice zone of extraction), yet what STS and CS experiences have shown is that bottom up initiatives can make the different positions more salient from the start. These conditions then facilitate the subsequent steps towards concrete actions. Note, however, that in many cases, the actual conformation of group identities, having explicit desires and goals, is not settled until after a series of reciprocal exchanges with other groups from society have taken place (Callon, Lascoumes, and Barthe 2009). In our case, it was the continuous dialogic exchange between members of the academies (students, teachers and scientists) that resulted in definite research goals (i.e. research questions and hypotheses), but the seeds were planted by the students in the first place. On the basis of the three main elements of the democratization of science – dialogue, openness, and reflexivity – and the critical and reflective approach proposed by several authors (Irwin 1995; Jassanof 2003; Wynne 1996; Delgado 2010), our model then contributes to a process of democratization of science where motivations and values of the actors are involved, and reflexivity is generated with self-critical capacity.

4.2. Learning outcomes

As noted in Section 1, there is a pending challenge for CS projects to measure learning before being incorporated into curricular activities (Kloetzer et al. 2021). We combined quantitative and qualitative tools and found positive evidence suggesting that our program promoted scientific competencies and socioemotional skills in students, complementing and extending previous reports (Perelló et al. 2017; Ruiz-Mallén et al. 2016; Schon et al. 2014; Silva et al. 2016).

Of the scientific skills in the research path, three were more engaged: curiosity, methodology, and communication. Each of these components has its own relevance but is connected to each other. Regarding curiosity, educators and psychologists have long recognized the important role it plays in scientific inquiry and learning, akin to a “physiological hunger” to learn (Engel 2011; Kidd and Hayden, 2015). The high scores observed in the rubrics complemented the reports of its engagement by the students. As one of them
remarked, keeping curiosity alive was important for his commitment to participate and to value the obtained results. Our findings, however, contrast with those of Silva et al. (2016), in which curiosity was the least competency engaged in their CS program. Yet this study used a guided inquiry design and students’ participation was not voluntary (it was part of a regular biology class). Studies have shown that automatic inscription in citizen science programs can be detrimental to raise students’ motivation (Kelemen-finan, Scheuch, and Winter 2018), which along with students having no participation in choosing the topic may explain their results and the differences with ours.

On the other hand, the methodological skills mostly exercised in our program were information-searching strategies and focalization to frame research questions. Learning strategies to search and criteria to filter information is of utmost importance to build the background of a project, skills that are especially relevant in our times where information overflows. For young students, this can be hard because much of the circulating information is misleading and criteria for selecting sensible sources may not have developed yet. In our program, the guiding role played by scientists was crucial in this respect, supporting the importance of experts to foster students’ learning (see also Hiller and Kitsantas 2014). Note that enhancing curiosity could also have contributed to promoting searching information strategies in our kids, consistent with recent theories of curiosity proposing that besides its motivating role, it helps focus on finding useful information from the environment (Kidd and Hayden 2015).

Along with curiosity and methodology, communication skills were also exercised in the program. Students presented posters in a congress and made videos with results, exhibiting appropriate use of language and clarity of expositions (the two aspects characterizing communication in our case). The kids who created videos were happy to know other ways of communicating science besides papers, this suggests that the use of non-traditional formats (e.g. blogs, social media, newspapers, etc.) can be successfully implemented in school CS programs. But regardless of the format of the presentation, students learned the importance of socializing and sharing scientific findings with the public. Also, it is possible that the importance of using specific terms in specific contexts may have helped students gain a deeper understanding of those terms and concepts. Exploring this possibility further, with specific tests aimed at measuring conceptual learning, can be an interesting avenue for future research. Interestingly, although communication is seen as the last step in the research path, in collaborative contexts, it may pervade steps all the way up. As noted by Bell, Urhahne, and Schanze (2010), when working in collaborative groups, participants need to constantly share ideas and reflect on outcomes throughout the entire research process, and communication is the key element of collaborative groups.

Furthermore, in intercultural contexts, communication has shown to play a crucial role when implementing educational programs. According to Reyes-Galindo and Ribeiro (2017), technology is an important aspect contributing to communication in intercultural territories, despite the socioeconomic inequalities observed in them. However, for communication to be useful in education, it is important to know the different views cultures have on education. This is a burgeoning field of research. In the Mapuche case, authors such as Daniel Quilaqueo, Elisa Loncon, and Segundo Quintriqueo have pioneered research promoting Mapuche’s educational methods. Elements such as the deep conversation (nütram), the recognition of multiple relations between human and nature...
(pentekum), the chanting and Mapuche poetry (ültkantun), and the narrated history and memories stored in storytelling formats (piam or piamtum) are elements to be included in intercultural Mapuche education (Quilaqueo, Fernández, and Quintriqueo 2020). More than a limitation, the incorporation of these elements into public educational programs is an invitation to explore novel educational practices that are significant and emerging from the very territories in which they are developed. This, moreover, is an emerging field of research in which this article contributes to the discussion.

In sum, our results point to positive outcomes of the EXPLORA program in three interconnected aspects of the research process, complementing previous reports and favoring the promising pedagogical value of school citizen science (Gray, Nicosia, and Jordan 2012; Kloetzer et al. 2021).

4.3. Scientific quality of the projects: towards a true school science

Soon after citizen science was born in the 1990s, skeptics questioned the quality of data collected by participants and suggested that no “real” scientific contributions (i.e. papers) could be expected from these collaborative experiences. Over the years, hundreds of CS investigations have produced concrete results (i.e. peer-review papers, changes in policies) thanks to the introduction of cross-validation checks, lowering these concerns (Bonney et al. 2014). In this line, we asked: can citizen science promote learning and scientific knowledge production in schools? The high scores reached by the academies in a congress of school science give support to this possibility. Moreover, at the time of writing this report, we knew that one of the academies of our program started drafting a manuscript to be sent to a journal. These reassuring results align with other experiences showing that students can be proficient at measuring (even more than adults) (Hiller and Reybold, 2011 cited in Hiller and Kitsantas 2014) and can produce scientific papers from collaborative research (e.g. Andújar et al. 2015). The wide scope and thorough treatment of topics shown in various international school science meetings also testify in favor of the productive potential of school science, as well as the case of Mrs Bingaman’s students showing that when organized and empowered, students can impact public policy (Schon et al. 2014), allowing them to develop a sense of agency to accompany their troubling awareness (Trott 2021).

Indeed, in addressing the perception of the quality of childhood, social studies of childhood have proposed that a preponderant focus on the achievements that children can reach as adults, wastes what they have to say and do in the here and now (OMG) (Qvortrup 2009). Kaufmann (2005) has called this “a structural indifference towards childhood on the part of society,” leaving children and adolescents without a voice in consequential decisions and actions that affect their lives (Vaghri 2018). Our results plus all the referred experiences above, however, indicate that it is imperative to conceive them as human beings rather than human becomings (Qvortrup 1985).

4.4. Building communities of school research

A long-term goal is that the academies born in our program thrive and propel a wave of enthusiasm towards learning science. We believe that this is especially significant in the
present territorial context, sadly marked by high levels of poverty and cultural fragmentation, but where people can gain the most out of innovative experiences in educational interventions (Freeman et al. 2014; Theobald et al. 2020). Though it is early to say if our program will help address this situation, it is important to safeguard the relational environment of academies so they can sustain long-term collaborations. Strengthening relationships between students and scientists has shown to have long lasting implications for students, influencing their self-efficacy, motivation, performance (Day and Allen, 2002 cited in Hiller and Kitsantas 2014), and even career election (Luzzo et al. 1999).

Testimonies from the interviews converged on indicating that relations became more horizontal and instilled with trust as academies developed. The trustful environment allowed some students to perceive their teachers as “partners” of research, and allowed teachers to realize that students’ abilities, besides those purely academic, such as self-determination, confidence, and empowerment were important for the success of the projects. Scientists on the other hand, were eager to collaborate and, in general, developed good relationships with students and teachers. However, some scientists manifested difficulties in aligning with students’ goals and attitudes. Thus, clarifying what are the expected contributions and responsibilities of the members of the group at the beginning of the program as well as providing some training activities to scientists who may not be familiar with school research can help prevent similar situations in the future.

The horizontalization seen within academies, reported in other studies as well (Peltola and Arpin 2018; Ruiz-Mallén et al. 2016), not only allowed participants to pay attention to socioemotional aspects but also to reflect upon ethical and political issues. Some scientists became explicitly aware of the value of and the urgency to connect with communities outside academia. This reflection hinges directly upon the democratizing character we expected to see from a bottom-up experience. This signals in a microscale a larger institutional political process on the way in our country. In 2019, a massive outbreak in Chile led to a constitutional process, which is ongoing and where a new social contract is being negotiated. In addition, a Science Ministry and a scientific policy have been recently created in the country, in which the democratization and linking of science with society is explicitly promoted (Ministerio de Ciencia, Tecnología, Conocimiento e Innovación 2020). One of the pillars of this manifesto, where the EXPLORA program is inserted, lies precisely in strengthening the institutional conditions that can favor a more direct, bidirectional link between science and the public. It is expected that by generating symbiotic links between scientific and educational communities, research lines from academia can merge with local socio-environmental concerns, building common agendas and contributing to a more sustainable and democratic development. A transition from delegated democracy to dialogic democracy is firmly on its way (Callon, Lascoumes, and Barthe 2009), in Chile, but in other regions of Latin America as well (Invernizzi 2020). The diversity of group identities and opinions are being validated and celebrated within society as much as the value of arriving at a consensus regarding complex and uncertain matters. We hope that children, teachers, and scientists in our program could have grasped the value of negotiating when being in groups.
4.5. Limitations and future

One methodological improvement will be to increase the sample size of the evaluations. Although we obtained quantitative results from more than 25 academies and interviews with 12 participants, we should still work to increase these numbers to strengthen the generalizability of our results. Previous studies that have faced similar issues (Silva et al. 2016; Vitone et al. 2016) and future implementations should motivate and explicitly indicate to participants the importance of their feedback. In the present intercultural context, this would allow further characterizations of academies upon the cultural background of their participants.

A second issue relates to measuring learning outcomes. The rubric we used provided a detailed picture of scientific competencies exercised during the program at the group level (i.e. academies) but did not generate a comparable measure at the subject level. To cope with this, we combed the rubrics with focused interviews, yet future projects may incorporate rubrics at the subject level (Perelló et al. 2017). This is important because not all students engage and learn in the same way within groups and detecting these differences may contribute to focalize the help for students that may lag behind their peers. Including these measures can be important in the intercultural context. Comparable instruments can be applied to teachers and scientists as well. Together, these tools may help detect dynamics of power inside groups (Gray, Nicosia, and Jordan 2012) and design experimental studies on the efficacy of CS programs. For example, they may help find out the optimal balance between guidance and freedom to achieve the most of these experiences using for instance “second-generation research” where different active learning scenarios are contrasted between each other (Freeman et al. 2014) and with respect to regular curricular activities.

Lastly, we shall define the conditions to foster enduring collaborations between school and scientific institutions. Our efforts got together 41 schools with 8 research institutions in these two years. To keep bonds alive, the EXPLORA team played the role as mediator or coordinator. We expect that these bonds may mature and consolidate autonomous units of partnerships. To this end, it is important that schools and research institutions can clearly see the benefits and responsibilities implied in such a union. In addition, schools are immersed in local communities where families and neighbors form tight groups and they should also be included in project designs. Finally, a commitment of the school staff to support teachers should also be pushed, as this aspect is important for the success of citizen science in schools (Kloetzer et al. 2021). Accomplishing all these goals implies significant efforts. The results we presented here are the first steps to reaching them.

Acknowledgements

The authors want to thank, first of all, the children and adolescents who contributed with their enthusiasm and dedication to the realization of this program. Their joy was an inspiration for all of us. We also thank teachers and scientists for their commitment and advice. Thanks to the schools’ staff members and directors for their help. Thank you to the reviewers for their helpful suggestions to improve this work.

Disclosure statement

No potential conflict of interest was reported by the author(s).
Funding
The authors acknowledge the financial support of Ministerio de Ciencia, Tecnología, Conocimiento e Innovación (EXPLORA program, ER190007, Chile), and of Agencia Nacional de Investigación y Desarrollo (ANID, doctoral scholarship 2020 / N°21202417, Chile).

Notes on contributors
Camilo Gouet Hiriart holds a Master's Degree in Neuroscience and Cell Biology from the University of Chile and is Doctor in Psychology from the Pontifical Catholic University of Chile. He has researched the neurobiology of memory and learning, and the design and implementation of cognitive training for early mathematical skills. He is currently researching games in collaboration with artificial intelligence researchers.

Daniela Salazar Rodríguez is an environmental biologist and holds a Master's Degree in biological sciences from the University of Chile. She has researched plant ecology and diversity. She has worked as a facilitator in outdoor education programs and in managing educational innovation projects. She currently works on participatory education and research projects.

Wladimir Riquelme Maulén is an anthropologist from the Alberto Hurtado University and holds a Master's Degree in Human Settlements and Environment from the Pontifical Catholic University of Chile. He has experience in university teaching, ethnographic documentary, and applied scientific research on the Mapuche people, Chilean rurality and cultural traditions.

Alejandra Rojo Almarza is a sociologist from the Alberto Hurtado University, she received a Diploma in Pedagogy of Coexistence from the Pontifical Catholic University of Chile, and in Good Practices for Educational Inclusion from the Catholic University of Temuco. She has experience in design, coordination and evaluation of projects in the fields of education for sustainable development.

Daniel Opazo Bunster is a biologist and Doctor in Ecology and Evolution from the University of Chile. He has worked in the management of educational innovation projects and in teaching with children, youth and adults. He has researched animal behavior, communication and learning. He currently works as director of the EXPLORA project and researches educational innovation.

ORCID
Wladimir Riquelme Maulén https://orcid.org/0000-0002-4586-3980

References
Albagli, S., and A. Y. Iwama. 2022. “Citizen Science and the Right to Research: Building Local Knowledge of Climate Change Impacts.” Humanities and Social Sciences Communications 9 (1): 1–13. doi:10.1057/s41599-022-01040-8.

Andújar, B., G. Campderrós, M. García, M. Marino, M. Mas, L. Narbona, L. Pérez, et al. 2015. “Twenty Tips for High-School Students Engaging in Research with Scientists.” Frontiers for Young Minds 3: 1–7. doi:10.3389/frym.2015.00007.

Ausubel, D. 1983. Teoría del aprendizaje significativo.

Bautista-puig, N., D. De Filippo, E. Maule, and E. Sanz-Casado. 2019. “Scientific Landscape of Citizen Science Publications: Dynamics, Content and Presence in Social Media.” Publications 7: 1. doi:10.3390/publications7010012.

Bela, G., T. Peltola, J. C. Young, B. Balázs, I. Arpin, G. Pataki, J. Hauck, et al. 2016. “Learning and the Transformative Potential of Citizen.” Conservation Biology 30 (5): 990–999. doi:10.1111/cobi.12762.
Bell, T., D. Urhahne, and S. Schanze. 2010. “Collaborative Inquiry Learning: Models, Tools, and Challenges.” *International Journal of Science Education* 32 (3): 349–377. doi:10.1080/09500690802582241.

Bonney, R., H. Ballard, R. Jordan, E. McCallie, T. Phillips, J. Shirk, and C. C. Wilderman. 2009. *Public Participation in Scientific Research: Defining the Field and Assessing its Potential for Informal Science Education. A CAISE Inquiry Group Report.* Online Submission.

Bonney, R., J. L. Shirk, T. B. Phillips, A. Wiggins, H. L. Ballard, A. J. Miller-Rushing, and J. K. Parrish. 2014. “Next Steps for Citizen Science.” *Science* 343: 1436–1437. doi:10.1126/science.1251554.

Callon, M. 1999. “The Role of Lay People in the Production and Dissemination of Scientific Knowledge.” *Science, Technology & Society* 4 (1): 81–94. doi:10.1177/097172189900400106.

Callon, M., P. Lascoumes, and Y. Barthe. 2009. *Acting in an Uncertain World: An Essay on Technical Democracy.* Cambridge, MA: MIT Press.

Claxton, G. 1994. *Educar Mentes Curiosas: El Reto de la Ciencia en la Escuela.* 1st ed. A. Madrid: Machado Libros S. A.

Clinio, A. 2019. “Ciência Aberta na América Latina: duas perspectivas em disputa.” *Transinformação* 31: 1–12. doi:10.1590/238180889201931e190028.

Cooper, C. B., C. L. Hawn, L. R. Larson, J. K. Parrish, G. Bowser, D. Cavalier, R. R. Dunn, et al. 2021. “Inclusion in Citizen Science: The Conundrum of Rebranding. Does Replacing the Term Citizen Science do More Harm Than Good?” *Science* 372 (6549): 1386–1388. doi:10.1126/science.abi6487.

Day, R., & T. D. Allen. 2002. “The Relationship between Career Motivation and Self-Efficacy with Protégé Career Success.” *Journal of Vocational Behavior* 64: 72–91. doi:10.1016/S0001-8791(03)00036-8.

Delgado, A. 2010. “¿ Democratizar la Ciencia ? Diálogo, reflexividad y apertura.” *Revista iberoamericana de ciencia tecnología y sociedad* 5 (15): 9–25.

Díaz-Barriga, F., and G. Hernández. 2002. *Estrategias docentes para un aprendizaje significativo. Una interpretación constructivista.* 2nd ed. Mexico City: McGraw-Hill Interamericana.

Durán, T. 1995. ¿Qué Tipo de Educación para la Población Mapuche en Chile? II Congreso Chileno de Antropología. Valdivia: Colegio de Antropólogos de Chile A. G, Valdivia.

Eitzel, M. V., J. L. Cappadonna, C. Santos-Lang, R. E. Duerr, A. Virapongse, S. E. West, C. Kyba, et al. 2017. “Citizen Science Terminology Matters: Exploring Key Terms.” *Citizen Science: Theory and Practice* 2 (1): 1–20.

Engel, S. 2011. “Children’s Need to Know: Curiosity in Schools.” *Harvard Educational Review* 81 (4): 625–646.

Freeman, S., S. L. Eddy, M. Mcdonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. Pat. 2014. “Active Learning Increases Student Performance in Science, Engineering, and Mathematics.” *Proceedings of the National Academy of Sciences of the United States of America* 111 (23): 8410–8415. doi:10.1073/pnas.1319030111.

Freire, P. 1999. *Pedagogia da Autonomia: Saberes Necessários à Prática Educativa.* Rio de Janeiro: Paz e Terra; Pedagogia do Oprimido: 17.

Gray, S. A., K. Nicosia, and R. C. Jordan. 2012. “Lessons Learned from Citizen Science in the Classroom. A Response to “The Future of Citizen Science.’” *Democracy and Education* 20 (2): 1–5. http://democracyeducationjournal.org/home/vol20/iss2/14.

Gurría, R. 2018. *PISA Results 2015 in Focus.* https://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf.

Hiller, S. E., and A. Kitsantas. 2014. “The Effect of a Horseshoe Crab Citizen Science Program on Middle School Student Science Performance and STEM Career Motivation.” *School Science and Mathematics* 114 (6): 302–311.

Hiller, S. E., & L. E. Reybold. 2011. “Field Expert’s Perceptions of Scientific Observations in the Natural World.” Presentation at the annual research symposium of the North American Association for Environmental Education. Raleigh, NC.

Invernizzi, N. 2020. “Public Participation and Democratization: Effects on the Production and Consumption of Science and Technology.” *Tapuya: Latin American Science, Technology and Society* 3 (1): 227–253. doi:10.1080/25729861.2020.1835225.

Irwin, A. 1995. *Citizen Science: A Study of People, Expertise and Sustainable Development.* London and New York, NY: Routledge.
Iwama, A. Y., F. Araos, J. Anbleyth-Evans, V. Marchezini, A. Ruiz-Luna, F. Ther-Ríos, G. Bacigalupe, and P. E. Perkins. 2021. “Multiple Knowledge Systems and Participatory Actions in Slow-Onset Effects of Climate Change: Insights and Perspectives in Latin America and the Caribbean.” Current Opinion in Environmental Sustainability 50: 31–42. doi:10.1016/j.cosust.2021.01.010.

Jassanof, S. 2003. “Technologies of Humility: Citizen Participation in Governing Science.” Minerva 41: 223–244.

Kaufmann, F.-X. 2005. Schrumpfende Gesellschaft. Vom Bevölkerungsrückgang und seinen Folgen (edición suhrkamp, 2406). Frankfurt am Main: Suhrkamp.

Kelemen-finan, J., M. Scheuch, and S. Winter. 2018. “Contributions from Citizen Science to Science Education: An Examination of a Biodiversity Citizen Science Project with Schools in Central Europe.” International Journal of Science Education 40 (17): 2078–2098. doi:10.1080/09500693.2018.1520405.

Kidd, C., and B. Y. Hayden. 2015. “The Psychology and Neuroscience of Curiosity.” Neuron 88 (3): 449–460. doi:10.1016/j.neuron.2015.09.010.

Kirschner, P. A., and R. E. Clark. 2006. “Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching.” Educational Psychologist 41 (2): 75–86. doi:10.1207/s15326985ep4102.

Kloetzer, L., J. Lorke, J. Roche, Y. Golumbic, S. Winter, and A. Jõgeva. 2021. “Learning in Citizen Science.” In The Science of Citizen Science, edited by K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, and K. Wagenknecht, 283–308. Cham: Springer Nature Switzerland AG.

Kullenberg, C., and D. Kasperowski. 2016. “What is Citizen Science? – A Scientometric Meta-Analysis.” PloS One One 11 (1): 1–16. doi:10.1371/journal.pone.0147152.

Luzzo, D. A., P. Hasper, K. A. Albert, M. A. Bibby, and E. A. Martinelli. 1999. “Effects of Self-Efficacy-Enhancing Interventions on the Math / Science Self-Efficacy and Career Interests, Goals, and Actions of Career Undecided College Students.” Journal of Counseling Psychology 46 (2): 233–243.

Ministerio de Ciencia, Tecnología, Conocimientos e Innovación. 2020. Política Nacional de Ciencia, Tecnología, Conocimiento e Innovación. Chile. https://www.minciencia.gob.cl/el-ministerio/politica-nacional-de-ctci/

Mueller, M., D. Tippins, and L. Bryan. 2012. “The Future of Citizen Science.” Democracy and Education 20: 1. Accessed http://democracyeducationjournal.org/home/vol20/iss1/2

Payás, G., and F. Le Bonniec. 2020. “Preface.” In Intercultural Studies from Southern Chile. Theoretical and Empirical Approaches, edited by G. Payás, and F. Le Bonniec, v–x. Cham: Springer.

Paytola, T., and I. Arpin. 2018. “Science for Everybody? Bridging the Socio-Economic Gap in Urban Biodiversity Monitoring.” In Citizen Science: Innovation in Open Science, Society and Policy, edited by A. Hecker, S. Haklay, M. Bowser, A. Makuch, Z. Vogel, and J. Bonn, 369–380. London: UCL Press. doi:10.14324/111.9781787352339

Perelló, J., N. Ferran-Ferrer, S. Ferré, T. Pou, and I. Bonhoure. 2017. “High Motivation and Relevant Scientific Competencies Through the Introduction of Citizen Science at Secondary Schools: An Assessment Using a Rubric Model.” In Citizen inquiry, edited by C. Herodotou, M. Sharples, and E. Scanlon, 150–175. London: Routledge.

Piñones-Cañete, C., C. Pastén-Tricallotis, and C. Jopia-Quinones. 2021. “Arte-ciencia en micorriza: una experiencia de aprendizaje integrado entre Biología y Artes Visuales en pandemia.” Revista Saberes Educativos 7: 157–171.

Quilaqueo, D., C. Fernández, and S. Quintriqueo. 2020. “Episteme for Intercultural Dialogue Between Mapuche Education and School Education.” In Intercultural Studies from Southern Chile. Theoretical and Empirical Approaches, edited by G. Payás, and F. Le Bonniec, 89–99. Cham: Springer.

Quilaqueo, D., and S. Quintriqueo. 2017. Métodos educativos mapuche: retos para una doble racionalidad educativa. Aportes para un enfoque educativo intercultural, edited by D. Quilaqueo, and S. Quintriqueo. Ediciones Universidad Católica de Temuco, Temuco.

Quilaqueo, D., S. Quintriqueo, H. Torres, and G. Muñoz. 2014. “Saberes educativos mapuches: aportes epistémicos para un enfoque de educación intercultural.” Chungara, Revista de Antropología Chilena 46: 271–283.
Qvortrup, J. 1985. “Placing Children in the Division of Labour.” In *Family and Economy in Modern Society*, edited by P. Close, and R. Collins, 129–145. London: Palgrave Macmillan.

Qvortrup, J. 2009. “Are Children Human Beings or Human Becomings?: A Critical Assessment of Outcome Thinking.” *Rivista Internazionale di Scienze Sociali* 117 (3): 631–653.

R Development Core Team. 2017. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. http://www.r-project.org/

Reyes-Galindo, L., and T. Ribeiro. 2017. “Introduction: Intercultural Communication and Science and Technology Studies.” In *Intercultural Communication and Science and Technology Studies*, edited by L. Reyes-Galindo, and T. Ribeiro, 1–21. Cham: Palgrave Macmillan.

Ruiz-Mallén, I., L. Riboli-Sasco, C. Ribault, M. Heras, D. Laguna, and L. Perié. 2016. “Citizen Science: Toward Transformative Learning.” *Science Communication* 38 (4): 523–534. doi:10.1177/1075547016642241.

Sanson, Ann V., Judith Van Hoorn, and Susie EL Burke. 2019. “Responding to the Impacts of the Climate Crisis on Children and Youth.” *Child Development Perspectives* 13 (4): 201–207.

Schon, J., K. Eitel, D. Bingaman, B. Miller, and R. Rittenburg. 2014. “Big Project, Small Leaders.” *Science and Children* 51 (9): 48–54. doi:10.25054/sc14_051_09_48.

Shirk, J. L., H. L. Ballard, C. C. Wilderman, T. Phillips, A. Wiggins, R. Jordan, E. McCallie, et al. 2012. “Public Participation in Scientific Research: A Framework for Deliberate Design.” *Ecology and Society* 17 (2): 29. doi:10.5751/ES-04705-170229.

Silva, C., A. J. Monteiro, C. Manahl, E. Lostal, T. Schäfer, N. Andrade, F. Brasilheiro, et al. 2016. “Cell Spotting: Educational and Motivational Outcomes of Cell Biology Citizen Science Project in the Classroom.” *Journal of Science Communication* 15 (01): 1–20.

Silva-alé, J. 2021. “Aprender vulcanismo mediante proyectos escolares: un diseño pedagógico con tecnología digital en contexto de pandemia.” *Revista Saberes Educativos* 7: 111–130.

Sullivan, G. M., and A. R. Artino. 2013. “Analyzing and Interpreting Data from Likert-Type Scales.” *Journal of Graduate Medical Education* 5 (4): 541–542.

Theobald, E. J., M. J. Hill, E. Tran, S. Agrawal, E. N. Arroyo, S. Behling, N. Chambwe, et al. 2020. “Active Learning Narrows Achievement Gaps for Underrepresented Students in Undergraduate Science, Technology, Engineering, and Math.” *Proceedings of the National Academy of Sciences of the United States of America* 117 (12): 6476–6483. doi:10.1073/pnas.1916903117.

Trott, C. D. 2021. “What Difference Does it Make? Exploring the Transformative Potential of Everyday Climate Crisis Activism by Children and Youth.” *Children’s Geographies* 19 (3): 300–308.

Vaghri, Ziba. 2018. “Climate Change, An Unwelcome Legacy: The Need to Support Children’s Rights to Participate in Global Conversations.” *Children, Youth and Environments* 28 (1): 104–114.

Vitone, T., K. A. Stover, M. S. Steininger, J. Hulcr, R. Dunn, and A. Lucky. 2016. “School of Ants Goes to College: Integrating Citizen Science Into the General Education Classroom Increases Engagement with Science.” *Journal of Science Communication* 15: 1. doi:10.22323/2.15010203.

Wynne, B. 1996. “May the Sheep Safely Graze? A Reflexive View of the Expert-lay Knowledge Divide.” In *Risk, Environment and Modernity: Towards a new Ecology*, edited by S. Lash, B. Szerszynski y, and B. Wynne, 44–84. Londres: Sage. (coords.)

Zimmerman, C. 2007. “The Development of Scientific Thinking Skills in Elementary and Middle School.” *Developmental Review* 27 (2): 172–223.