"We are not being taught sustainable citizenship!": Podcasts for critical science literacy in teacher education

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Education on sustainability is a crucial goal that requires a transformative shift in teacher education to drive meaningful changes oriented to action. A cross-sectional study with an exploratory design investigated preservice science teachers' perceptions regarding teaching sustainable citizenship, specifically focusing on the climate crisis and earthquakes-tsunamis. The study was conducted in two Chilean universities with similar teacher preparation programs. The team designed a podcast series, which was used and evaluated by the 13 participants through action research. Three group discussions explored their perceptions of the resources, as well as the aims and challenges of teaching sustainable citizenship and the podcasts. We used Grounded Theory steps, including triangulation by the researchers to ensure reliability, to qualitatively analyse the data. The results reveal a constraint on teaching in areas where the participants lacked the necessary preparation and background knowledge as students and preservice teachers. The main challenges were related to interdisciplinarity, the social dimension of socio-scientific issues and context-responsive teaching methods. The perceived aims were the development of students' critical thinking, informed positioning, and encouraging active citizen participation. Preservice teachers found the podcast series to be a valuable new epistemic and pedagogical resource that can support their efforts to teach sustainable citizenship and implement pedagogical strategies. The autonomous usage of the device triggered reflection processes, particularly regarding the human rights perspective, which unveiled the socio-political dimensions inherent in science education. It promoted personal re-positioning as active citizens and educators and empowered them to seek out and pursue the changes needed to reshape future classrooms. We discuss these findings in the context of teacher preparation and the use of educational technology in teacher education.

Keywords: initial teacher education, sustainability, podcasts, chemistry preservice teachers

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1 Introduction

One of the foundational premises of the research reported in this article is the connection between science education and civic education. An example of this link is the socio-scientific inquiry-based learning (SSIBL) framework, which proposes a model of inquiry-based teaching practices that advocates integrating citizenship education into science classes (Levinson, 2018). Similarly, the European Commission report 'Science Education for Responsible Citizenship' (Hazelkorn et al., 2015) highlighted the critical issues in promoting a form of science education that provides the necessary knowledge for students to participate in society actively and responsibly during their school years and throughout their lives.

In the context of science education, it is also necessary to consider the concept of sustainable citizenship as a central axis in the connection between science education and citizenship. It relates to the notion of active and participatory citizenship, as teaching should motivate students to make sustainable changes within their own sphere of influence (Westheimer & Kahne, 2004). This connection does not seem to occur frequently regarding local and global challenges faced by societies (Hayward, 2012). Such a connection emphasizes that citizenship is not just a legal status within a political community, but also generates of a sense of belonging in people that allows them to critically participate in their community, which can extend far beyond local or national boundaries (Veugelers, 2021).

Sustainable citizenship is also linked to the knowledge, protection, and defense of human rights, particularly economic, social, cultural, and environmental rights. These rights were guaranteed in the International Covenant on Economic, Social and Cultural Rights (ICESCR) of the United Nations in 1966 and the San Salvador Protocol of the OAS in 1988, which refers to rights related to economic and social conditions necessary for a dignified life, including the right to work, health, education, food, water, housing, a healthy environment, culture, and security. These rights are distinct compared to other human rights in that they have been defined as progressive, meaning that states are expected to progressively fulfill these obligations as their socio-economic situation allows. How these rights are fulfilled or exercised can vary depending on development, especially in science and technology, which can create new conditions of well-being.

In this sense, teaching environmental issues and sustainability involves complex and controversial socio-scientific problems which students must address critically (Hayward, 2012), including from a human rights perspective. While science teacher

education for sustainable citizenship is a recent global aim, it is critical in developing countries, i.e., in the global south or Latin America (Medina-Jerez, 2018).

Based on research in chemistry education in the global north and south, theoretical frameworks that are coherent with the current study have emerged about what, why, and how to teach chemistry. These frameworks point to the integration of disciplinary, epistemic, and contextual elements for the development of critical scientific literacy, such as humanistic chemistry (Sjöström & Talanquer, 2014), relevant chemistry education (Eilks & Hofstein, 2015), school chemistry for citizenship (Santos, 2011; Marzábal et al., 2021) and context-based chemistry teaching (Caamaño, 2018). It should be noted that these approaches are more pertinent to contents related to sustainable chemistry. However, such approaches share convergences with broader areas of the discipline that involve a) identifying central ideas of and about chemistry with explanatory power and an informed vision around the nature of chemistry, b) introducing socio-scientific issues of personal, local and global relevance as a starting point, and integrating them into the contents to be taught c) re-defining the purposes of scientific literacy to promote individual and collective well-being, the generation of transformative actions within the territory, participation in the socio-scientific debate, and responsible decision making on sustainable development issues related to chemistry (Mamlok-Naaman et al., 2018). Other contributions look for synergies between chemistry education and sustainability education. For example, Mahaffy et al. (2017) emphasize the importance of understanding climate change as a rich context for chemistry teaching. Talanquer (2016) proposes a set of core teaching ideas, including sustainable action, on which the development, distribution, and consumption of chemical products entail benefits, costs and risks that need to be identified, evaluated, and publicly discussed for the improvement of the human condition and the respect for environmental quality, as primary goals.

In the evolving landscape of biology education, there is a critical and recognized need to go beyond conventional teaching methods and address pivotal socio-scientific and sustainability issues (e.g., Vilches & Gil Pérez, 2007; Céspedes, 2020). It can integrate essential topics like ecosystem services, genetic modification, and disease ecology into the curriculum by incorporating active teaching strategies such as problem-based learning, outdoor education, and collaborative inquiry. By designing biology learning experiences that emphasize student inquiry, collaboration, and real-world problem-solving, we commit to nurturing informed, proactive participants in both the

scientific community and the broader societal movement towards sustainability (Jeronen et al., 2017).

Educators are thus challenged to design biology learning experiences that provoke student inquiry, dialogue, and action on real-world issues, aligning with the broader goal of promoting active, informed participation in the scientific and societal discourse.

Physics education is pivotal in equipping students with foundational knowledge and the ability to understand the principles present in the natural world, from subatomic particles to the vast universe. As students explore energy conservation, thermodynamics, and electromagnetism, they gain insights into critical issues like renewable energy, climate change, and technological innovation. Incorporating these global challenges into physics education has proven to be difficult; for example, teachers lack explicit strategies to cope with the challenges of teaching socio-scientific issues and additional support is needed to improve the quality of implementation (Chen & Xiao, 2021). Nevertheless, it makes the subject more relevant and engaging and prepares students to critically analyse and address society's technical and environmental dilemmas. By emphasising the societal and ethical implications of physical principles, physics education fosters a generation of learners who are not only scientifically literate but also capable of contributing to a sustainable future through informed decision-making and responsible citizenship (e.g., Costa et al., 2023; Hoque et al., 2022).

Consequently, these frameworks pose the need to design formative actions for science teachers that allow them to question their beliefs and knowledge, collaborate with peers, and articulate their teaching and evaluation practices. Achieving this goal requires transforming teacher education to cultivate both general and specific knowledge and skills that allow future teachers to evaluate and make decisions about products, technologies and processes based on chemistry (Burmeister et al., 2012). It also requires redefining the aims of teaching and learning processes and their methods to contribute to the consolidation of teaching sustainable citizenship in secondary and higher education (Santos, 2011). As we mentioned before, in our view, citizenship includes a human rights perspective; thus, teaching science for sustainable citizenship should explicitly take this focus.

Despite the importance that environmental research places on the role of citizens in mitigating climate change and the relevance that teachers place on education about sustainable development (Hogan & O'Flaherty, 2021), large-scale surveys provide evidence that global understanding of climate sustainability is far from satisfactory (Jin

et al., 2015). The limited knowledge about climate sustainability may be related to the difficulty of understanding some scientific concepts or because the underlying scientific reasoning may be counterintuitive (Jin et al., 2015). Similarly, in socio-scientific areas that are key to people's lives, there is little research on how teachers learn to teach the social and pedagogical dimensions, which could improve classroom learning (Gray & Bryce, 2006). Consequently, there is a need to search for or create strategies to promote critical thinking regarding the phenomena (Jin et al., 2015) and apply them to decision-making in the real world (Cutting & Kelly, 2015).

One such strategy is the use of podcasts. There is limited evidence regarding their use in secondary science education, which has been focused on students creating podcasts as an assignment (Gil & Ortega-Quevedo, 2021; Pegrum et al., 2014). Indeed, there are conflicting views in this area. Drew (2017) argues that podcasts enrich classes often dominated by texts or online modules. They are a tool with ample flexibility to deliver information asynchronously, safely, and inclusively (Strickland et al., 2021). Some examples of podcasts associated with the sciences include "Materialism" (Falkowski & Sparks, 2020) and “AsistEd Podcast” (Pollock et al., 2020). On the other hand, Pegrum et al. (2014) claim that just listening to a podcast made by someone else does not significantly affect student learning.

Other results regarding its effectiveness on student performance are diverse and contradictory. Heilesen (2010) found that podcasts did not significantly improve student performance, measured in grades, whilst Kay (2012) observed that video podcasts had a beneficial impact on student performance measured by test scores, skills, and practical tasks. Therefore, the results on this topic are inconsistent (Fernandez et al., 2015). Merino and Freire (2023) suggest that further action-research is needed.

Given the inconclusive results and scarcity of studies on teacher education using podcasts, the present study investigated the perceptions of preservice science teachers (Chemistry, Biology and Physics) on teaching science for citizenship. It also assessed the strengths and areas for improvement of a podcast series specifically designed for their professional development. The inclusion of these areas of science teacher education fulfills the requirement to integrate sustainable citizenship into secondary education, as mandated by the Chilean curriculum (details in study context).

2 Background and research questions

2.1 Study context

Science teacher education programs in Chile are facilitated by universities and typically span a duration of 10 semesters. Throughout this period, prospective educators are required to engage in coursework that is structured across three primary domains: 1) disciplinary education, pertaining to the specialized knowledge of the subject matter they intend to teach; 2) disciplinary-pedagogical education, which is interconnected with the instructional and learning methodologies specific to their disciplines, encompassing pedagogical theories and practical teaching experiences; and 3) professional development, encompassing modules focusing on ethical considerations, community engagement, and reflective practices pertinent to teaching. Moreover, these programs do not directly integrate courses dedicated explicitly to the themes of citizenship education, sustainability, or human rights. Rather, these themes are integrated into disciplinary-pedagogical education modules, where the extent of coverage is contingent upon the pedagogical approach of individual instructors.

This may be perceived as a limitation within the realm of initial teacher education, particularly given that the national curriculum mandates that science educators address the subject of 'science for citizenship' during the final two years of compulsory schooling. This is because in 2020, Chile's curriculum underwent a major shift from traditional disciplinary teaching towards integrated science teaching (MINEDUC, 2019). Currently, the last two years of secondary science education have a course oriented towards science for citizenship through modules that include socio-scientific issues. In the practice, due to the shortage of science teachers, the course is not taught collaboratively, which requires each teacher to integrate the disciplines into their lessons. However, teacher education programs still teach the disciplines separately.

2.2 Studies about podcasts in higher education

In the last 20 years, educational podcasts have emerged as a versatile tool in higher education. An educational podcast is a visual or audio medium of disciplinary content developed from a didactic planning process by a teacher, student, company, or institution (Solano & Sanchez, 2010). Podcasts are characterised by delivering content that can be listened to or viewed freely through any device (fixed or mobile) with an

Internet connection and can overcome the barriers of time and place for their convenient use by anyone (Solano & Sánchez, 2010).

By expanding the times and places where it can be accessed, the podcast has the particularity of broadening the teaching-learning process from the classic study contexts to any other context of the listener's choice. It makes it possible to take advantage of leisure or waiting times (Piñeiro-Otero, 2012). In addition to the usual subscription and updating of content, other reported advantages are the simple dissemination of content, its rapid and broad reach to a general or specific audience, and the diversification of teaching resources (Solano & Sánchez, 2010). Finally, the possibilities of expression, interaction and community building have also been recognised (Geoghegan & Klass, 2005).

In general, three main uses of educational podcasts have been identified in specific areas of higher education (Fernandez et al., 2015). The first, which McGarr (2009) defines as *substitutional*, refers to independently disseminating the disciplinary content of a specific course or area of knowledge. In some cases, they are used to deliver non-face-to-face training (Celaya et al., 2020). The second, called *creative*, includes podcasts in which students produce, capture, and preserve audio or video records to communicate their understanding of a particular topic (McGarr, 2009). Finally, the third use is *supplementary* to instruction or learning processes. This use has been crucial in supporting the understanding of complex topics through students' autonomous use of podcasts (Heilesen, 2010). Notably, the predominant use has been the dissemination of course content, as evidenced in extensive educational repositories such as Higher Education Podcast Repository and iTunesU, and its use for other purposes is still incipient (Fernandez et al., 2015). However, its use for scientific dissemination has been recorded since 2012 (Celaya et al., 2020).

The growing interest in the use of podcasts in education has also led to an increase in research on this phenomenon. Still, the focus of podcasts in education has been content dissemination or evaluation of students' learning processes rather than as a tool for supplementary pedagogical use. The research in the field has been concentrated on the process of creating podcasts and presenting general results (Fernandez et al. 2015; Merino & Freire, 2023). For example, we know that educational podcasts are accepted by students and are considered a valuable tool in the self-management of study habits (Heilesen, 2010). Similarly, Kay (2012), in his review on video podcasts -videocast or vodcast- compiled benefits observed in study habits such as fostering independence, self-reflection, preparation for exams, review of material and

increased contact with academic staff. This type of podcast is characterised as motivating and is positively valued by students, who highlight the possibility of learning anywhere, at any time and pace (Kay, 2012; Merino & Freire, 2023). However, it has also been reported that not all students find this tool valuable to their study techniques (Kazlauskas & Robinson, 2012), and some prefer face-to-face lectures due to the possibility of asking questions and interacting with the teacher (Kay, 2012).

Specifically, in science teacher education, the evidence on the supplementary use of podcasts or similar resources is both limited and varied, necessitating new research to investigate it on the learning process of teachers (Gullotti, 2017).

Therefore, the research questions of the current study were:

1. What objectives and challenges do preservice science teachers perceive in teaching science for sustainable citizenship?
2. According to preservice teachers, what are the strengths and areas for improvement in a podcast series designed for professional development in sustainable citizenship?

We investigated the perceptions of preservice teachers from Chemistry, Biology, Physics and General Science backgrounds, considering their imminent need to teach a curriculum that includes topics related to science for sustainable citizenship. For simplicity, we will refer to them as preservice science teachers, as the inquiry process did not reveal any differences based on their main disciplinary area.

3 Research Methods

3.1 Study design

The study had a cross-sectional exploratory design. The data collection process was aimed at capturing the participants' perceptions at a single point in time. We followed the guidelines of action research applied in science teacher education. This approach involves researching a phenomenon and proposing actions to improve or transform the participants' experience (Efron & Ravid, 2019). The scope was descriptive and relational, aligning with a participatory research paradigm, which considered the participants' perspectives (Bergold & Thomas, 2012). The epistemological belief that supported this decision is that each participant in the teacher education program has a valuable perspective on the challenges and objectives of teaching science, as well as the strengths and areas for improvement in a podcast series designed for their

professional development. Moreover, the group discussions allow participants to co-construct knowledge about these study objectives. Accordingly, the perspectives of this study follow an interpretive framework through which individuals make sense of the world (Woods, 1992).

3.2 Sampling and participants

The sampling process was purposeful and aimed at selecting typical cases (Patton, 2001). The two universities selected were representative of science teacher education in Chile. In both institutions, the preservice teachers usually start with science courses in the first years, then gradually take pedagogy courses, and by the end of the program (fourth or fifth year) they have practicum and teaching methods courses. Access to these universities followed a convenience criterion because the researchers taught there. However, the invitation for students to participate was delivered in accordance with the ethical guidelines detailed in the following pages and avoiding conflicts of interest. Table 1 summarises the participants' disciplinary areas by university:

Table 1. Participant's disciplinary areas by university

Participant number	University number	Area
1	1	Chemistry
2	1	Chemistry
3	1	Chemistry
4	1	Chemistry
5	1	Physics
6	1	Physics
7	2	Physics
8	2	Physics
9	2	Biology
10	2	Biology
11	2	Biology
12	2	Biology
13	2	Sciences

3.3 Podcasts design and implementation

The research team worked on the design of the podcast's scripts. The team consisted of a specialist in chemistry teaching, a specialist in physics teaching, a specialist in social science teaching, two psychologists serving as research assistants, and a novice teacher. The topic selection was part a broader research project (FONDECYT Regular

1221716), aimed at improving teacher education in citizenship science regarding two phenomena: the climate crisis and earthquakes-tsunamis. These scripts presented the phenomena in connection with human rights and discussed the main controversial component of each phenomenon from a teaching perspective.

The podcast series was in the format of an interview with a moderator and two teaching specialists. We included a brief news segment at the beginning of each episode to provide context, along with reflective questions on how to address the topics in the classroom, delivered by two novice teachers. The idea was to start with this motivational part and conclude with direct questions aimed at the targeted audience -preservice science teachers- about the controversial aspects of teaching each of the chosen sustainability topics. The purpose and reflective questions of each episode are shown in Table 2. The episodes can be accessed here https://osf.io/zdvu3.

Table 2. Purpose and description of podcast episodes.

Episode	Purpose	Description
1	To highlight the link between education for sustainable development and a human rights approach. This connection aims to advance social justice from a human rights perspective by overcoming extreme poverty, avoiding patterns of indiscriminate consumption and environmental degradation, and promoting inclusion and gender equity.	In this episode, two experts specializing in science education and human rights education explain their perspectives of education for sustainable development. It focuses on economic growth, the evaluation of cost, and the benefits of individual and collective actions. Through comments on popular culture, human rights are linked to education for sustainable development, and the speakers advocate that sustainability education should embrace a human rights approach to foster social justice, inclusion and gender equality. A question posed for listener reflection is 'How can we demonstrate that our teaching practices are developed from a human rights perspective?'
2–3	To highlight the scientific and social causes of climate change and its consequences. This connection aims to advance towards social justice from a human rights perspective, focusing on energy poverty, environmental degradation, and the differentiated impact according to socioeconomic status and gender.	This episode delves into a discussion about science education in the context of the climate crisis, analyzing the importance of understanding fundamental scientific concepts of extreme weather phenomena. Drawing from various disciplines, it highlights the need to integrate diverse knowledge to tackle the complexity of the climate crisis. The importance of science education for citizenship is emphasized by enhancing both comprehension and proactive engagement–pointing out that the impacts of this crisis vary significantly across different social groups, underscoring the need for a human rights approach to ensure that resilience-building efforts are equitable and inclusive, effectively mitigating the disparate effects of climate change. Two pivotal questions posed were: 'Have you reflected on the teaching of climate change as a socio-scientific phenomenon from a human rights perspective?' and 'What dialogue spaces can we open?'

4	To highlight the scientific and social causes of socio-natural disasters, earthquakes and tsunamis. This connection aims to advance social justice from a human rights perspective, focusing on understanding these phenomena with equity lenses that include gender, age, and socioeconomic status.	This episode reflects on the idea that disasters, specifically earthquakes and tsunamis, are socio-natural, not merely natural, within the scope of scientific education in Chile. The discussion explains the necessity of perceiving science as a human endeavor, full of ethical considerations and closely linked to social justice and local communities. We delve into scientific explanations for these events, particularly through the theory of plate tectonics, while emphasizing the compounding impact of social factors. By debunking common myths surrounding these phenomena, it underscores the need for education to provide people with the knowledge to navigate the complexities of socio-natural disasters and offers some methods for incorporating these topics into the education curriculum, advocating for an interdisciplinary vision and a context-aware teaching strategy that improves student understanding and preparedness for natural disasters. One of the questions posed for reflection is: 'Have you considered how to work on or teach these phenomena that can lead to disasters from a human rights perspective?'

The four episodes were recorded and edited in Spanish, and some sound effects were added to give the narrative a sense of realism and dynamism. The shortest episode was 17 minutes, and the most extensive, 27 minutes. The preservice teachers had one week to listen to the episodes in the order and time they chose. After the week ended, we invited them to participate in group discussions to assess the experience.

3.4 Ethical considerations

We followed the ethical guidelines to collect, process, and protect the data gathered in this research. The complete process was approved by the Pontificia Universidad Católica de Chile Social Sciences Ethics Committee under the protocol revision number 210728001. We ensured anonymity during data collection and storage, maintained confidentiality, used secure storage for both the raw and processed data, and controlled access to the datasets.

We did not reveal the participants' names or identities in any data analysis steps; pseudonyms were used to mask their real names and they referred to each other as such during the discussions. The transcriptions of the participants' discourse ensured anonymity in the datasets. Moreover, participation was voluntary, and participants had the right to resign at any time. If a participant left, their information was separated from the dataset and not analysed.

The participants signed an informed consent, approved the use of their data for research purposes, dissemination, and the proposal of new courses or similar endeavours to enhance teacher education. The authorities at their universities signed an authorization to note taking in group discussion meetings and the use of the information for research purposes. To maintain confidentiality, only the research team had access to the data. The information was stored in a secure, locked office and backed up in the cloud with password protection to ensure controlled access and data protection.

3.5 Data collection and analysis

Three approximately 90-minute group discussions were held with 13 participants to explore their perceptions of the objectives and challenges of teaching science for sustainable citizenship. These discussions also involved their evaluations of the strengths and areas for improvement in a podcast series designed for their professional development.

Qualitative analysis was conducted following Grounded Theory steps, with researchers employing triangulation to enhance reliability. Grounded theory is a qualitative research method (Glaser & Strauss, 2017). It aims to generate theories or new ideas grounded in data rather than testing pre-existing hypotheses. As the autonomous usage of the podcast series about sustainability topics was an under-explored topic in this group, we decided the steps of this method were suitable for this purpose. The data collection steps, and analysis are described below. Nonetheless, as it was an iterative and flexible process, these steps may have overlapped to understand the essence of participants' experiences and perspectives.

- Data Collection: We recorded and transcribed the three group discussions verbatim. The recording was solely audio, and backup recordings were made. In each meeting, a researcher -coauthor of this article- carefully documented non-verbal cues, such as body language and expressions, as they can provide additional context to interpret the verbal ideas expressed.
- Open Coding: We segmented the data into discrete parts and labelled them with codes. The codes were derived from the participants' ideas, concepts, and themes as much as possible, without trying to fit them into a preconceived framework. This approach was selected to allow patterns and categories to naturally emerge from the discussions.

- Axial Coding: We identified relationships between codes and organised them into broader categories. In this organisation, we looked for connections and interactions between different codes. This step helped us develop a more refined and interconnected set of categories to interpret the results.
- Selective Coding: We focused on the most significant and central categories that emerged from axial coding to develop a core category that captured the central theme or concept around which other categories revolve.

4 Results

To address the first research question, the results section is organised according to the aims, challenges, and resources as perceived by the participants regarding teaching sustainable citizenship. The second research question is answered regarding strengths and areas for improvement in a podcast series. The most salient categories are described first, followed by the codes that appeared less frequently.

4.1 Aims of teaching science for sustainable citizenship

The two most frequent aims of teaching science for sustainable citizenship, as reported by the participants, were the development of **students' critical thinking** skills and the provision of opportunities to **take a personal position** on controversial topics. This may involve adopting a new position or reaffirming a previous one based on critically analysed information. Linked to the decision-making process, this informed position implies that students engage in research, analyse sources, cases, and other information. Critical thinking was understood as helping students compare sources, question information, and distinguish trustworthy news from fake news as part of developing 21st-century skills.

> "It can be linked closely to this idea of generational or social knowledge about earthquakes and tsunamis and see how certain beliefs are myths. Some ideas that society has are not accurate or correct, regarding how society thinks they are. I believe that their critical thinking on this topic could be developed by questioning what they have been told about these phenomena." (Participant 9).

> "(...) For example, with climate change, many groups do not believe in climate change. Pupils can be constantly confronted with that idea in social networks or the news and may not have accurate information. I feel that an important part of what teaching for sustainable citizenship wants to focus on in the classroom is how to generate critical thinking in students about what they're seeing, what they're observing here, in the news, on TikTok. Twitter tells me this, but

> is it really like that? or can there be like nuance in what they are telling me?" (Participant 2).

Another key objective was described as encouraging **active citizen participation**. This refers to forming links within communities to drive action, promote change and participate in collective actions. This includes both the individual citizen dimension and involvement in communities and groups, such as neighbours or family members. It also involves being active in analyzing social media; motivating schoolmates to take environmental action, among other actions to encourage other people to move in the same direction.

> "Maybe I am too idealistic, but I believe that those of us who move in pedagogy have perhaps classrooms of 40 pupils, or more in some cases, and perhaps one could think 'of these 50 or 40, how many of them really learned? or how many perhaps reached the skill that is targeted in the aims I proposed?' I believe that regardless of this, persisting and repeating all this, they still have part of the knowledge from the lesson. Even if they have not achieved the skill or done well in the test, the pupils still get something important, an important part of this knowledge. For instance, something to discuss at home, to comment on with their friends; they all have social networks, they would have learned something, and they can see a publication in a social network and comment on it, maybe they have learned something new. They can generate something different from there" (Participant 10).

Other aims mentioned less frequently are related to **political action awareness**, i.e., becoming aware of decisions at the local and/or global government level; **acknowledging/valuing other knowledge sources**, such as ancestral or local community knowledge; and **changing pupils' behaviour** to encompass more sustainable actions. Here is an example of each of these aims:

> “And also, now thinking, you mentioned politics, nowadays we have many changes, many political poles, so having scientific arguments as to why certain political decisions are reflected in the vote itself, are also necessary, it is very important” (Participant 13).

> “(...) Chile is a seismic country; many generations have lived through earthquakes. It is not like climate change; we are the first generation living with climate change of this magnitude. On the other hand, with earthquakes, as there are several generations, several large earthquakes have occurred, and a lot of popular and social knowledge has been built from that, so I guess it is important from a socio-scientific approach. Preserving the ancestral knowledge that one can say, hey, it has a lot of meaning and it is really useful to discard the myths that can also generate misinformation" (Participant 8).

> “I feel that an important part of the science for sustainable citizenship course is, one, to generate a position in the students regarding the phenomena we are dealing with, and another, to modify their behaviour, which was something that stuck in my mind with our teacher guide we had at school, where we had the internship in the previous semester and where we had science for citizenship. And she was constantly telling the students that the objective of the course was to change their behaviour to make it better, based on what the science said” (Participant 2).

4.2 Challenges of teaching science for sustainable citizenship

Regarding the most frequently perceived challenges, teaching including **interdisciplinarity,** was the most salient. It contemplates the challenge of interdisciplinarity, given that preservice teachers were trained from a single-discipline or dual-discipline, often with similar perspectives (e.g., biology-chemistry). This challenge was expressed in the following quotation:

> "I have not had the opportunity to teach a course or take a course about sustainable citizenship, but (...) one of the things that is the most complicated for me is the interdisciplinarity [talking about practising micro-teaching in sustainable citizenship]. Because I knew how to explain the concepts separately, and there were... I don't know, physics, biology, it was not so complicated, but trying to integrate them all into a more general explanation was much more difficult, as I didn't know which link was the most... not necessarily perfect, but the most correct to bring all these subjects together at the same time, it was very complicated for me” (Participant 4).

Additionally, using socio-scientific controversies was perceived as very challenging for this group of participants, a point that arose multiple times during the group discussions. This approach meant integrating the individual versus collective or global dimensions of socio-scientific controversies, confronting widely spread myths and the diverse opinions that generate them, and expanding the social dimension of controversies in scientific issues. An example of this can be seen in this excerpt:

> “Eh, I think that...an important tension is finding a balance between how much one individual can do and how much we can do as a collective. I feel that students sometimes have a hard time envisioning how this collective perspective is going or the extent to which one can contribute, as an individual, to the group to face these crises” (Participant 8).

Another challenge mentioned in this study was considering the learners' context when teaching science for sustainable citizenship. This was observed, for instance, in the suitability of resources to engage international students, considering the diversity

of human, cultural, social, geographical, and political realities of the pupils' contexts. Likewise, the need to play multiple roles while teaching was also considered challenging. Among these roles were disseminating science, critically developing students' thinking, and managing the numerous emotions that appear when teaching sustainability topics. Participants perceived a need for constant preparation in knowledge, theories, lesson planning and the adoption of active teaching methodologies to address these aspects of teaching, which require multiple skills and a deep understanding of the topic. This idea is expressed in the quotation:

> "In my head, I had been thinking about how to involve the students, everyone, in what one is talking about, in this case, the climate crisis and earthquakes and tsunamis. And I think that as a teacher you have to go and do many things at the same time, you have to be a disseminator and know how to disseminate, because to do something, to communicate something, you have to be interesting to catch their attention and I think that closeness is one of the most important factors and one of the most relevant ones here" (Participant 3).

4.3 Resources for teaching sustainable citizenship

Regarding the resources identified by the participants, they highlighted the importance of working on local security plans, such as school evacuation plans, in case of emergencies like flooding, earthquakes, or fires due to the climate crisis and heat waves. They mentioned integrating pupils in the design, implementation, simulation and questioning of territorial or school security plans. For instance,

> "Likewise, taking this from operation Deyse [an evacuation and safety program for Chilean educational establishments in the event of natural phenomena] that students must take these measures as more contextual, rather than general. Perhaps a good activity could be to conduct the same operation Deyse, but in their homes, and in this way, you can also improve their critical thinking about where they have to exit, what things have to be clear, and what things have to be at hand when such an emergency occurs" (Participant 9).

This is also connected to another pedagogical resource, teaching from a territorial contextual perspective, i.e., based on a well-defined context of the students or the territorial perspective of each school. This idea is expressed in the quotation:

> "(...) I think an important part is to design contextualized responses. Because every building, every space where they live is different, there is no single great plan that works for all aspects and in all places. If there were, it would be great, but generally there are evacuation zones, there are evacuation routes. And I think it is important that students question and understand why one route is

> better than this other route that has four floors above, for example, or why do we want to go through a clear place instead of a place where there are light posts, to give an example. Designing these types of contextualized responses also brings information from the local territories and helps generate more critical knowledge about it" (Participant 8).

Pedagogical resources also included debate, argumentation, and role-playing to encourage pupils to critically discuss how to evaluate evidence versus a traditional lesson methodology. Regarding this matter, one participant explained:

> "(...) talking about strategies that can be used, I think that in these contexts role playing is very relevant, working, for example, with situations that may not be problematic but rather controversial (...) for example, I came up with the idea [to ask] why people build constructions on hillsides, even though it is known that there are landslides on some occasions? There is also the part that maybe there is not enough land for all the people. So, the role-playing exercises where we can see different points of view and where we can discuss and listen to others, I think that this is a strategy that can be very enriching." (Participant 12).

Reflective questions, which can deepen student discourse and test prior socio-scientific knowledge, allow teachers to share personal experiences, and appeal to emotional aspects, are examples of resources that were less frequently reported by participants. One such example is:

> "I tried to do a well-structured class, but in the second [class] (...) it happened that I shared a personal experience regarding climate change because of the fires, because I was living through the fires there in Chillán, in Ñuble [cities], I had to help, seeing the whole context. So, I talked about it in the micro-teaching and then the feedback I got was that it engaged the viewer, as well as asking a few more questions" (Participant 6). "I think the issue of emotion or how to engage the student is... it starts there, I don't think it's so much about the content itself. I think that if we get to the heart of the matter, like the issue of emotions, I think that's where it starts" (Participant 6).

The second research question explored the aspects that participating preservice teachers perceived as strengths and areas that needed improvement in the podcast series. The following results section describes both elements.

4.4 Strengths

One of the main strengths highlighted by the participants was the inclusion of reflective questions at the beginning and end of each podcast. It enhanced participant engagement and reflection processes regarding the socio-political dimension of science education. For instance, questions regarding how to integrate a human rights

perspective in their future pedagogical practice favoured a re-positioning as educators. They expanded their imagined repertoire of teaching methods, as shown in the following quotation:

> "I would like to mention that I found it interesting that a podcast on human rights was made; I did not know they were related. The podcast asks a question at the end, as in your early practicum: how do you see this in the dynamics? I have not had any early practicum and thank goodness I did not because I did not know they could be connected. Because teaching it from the basis that you have human rights over the environment and you have to respect them, but how will I respect something if I don't know what I have? So, it is essential to teach it, and it caught my attention because I did not know it, and I learned it for everyone, and I am going to have to teach it to them [to the pupils]" (Participant 10).

Moreover, the podcast series shows integrations between scientific disciplines and other socio-political visions, such as human rights, enacting an interdisciplinary perspective. Disciplinary integration was previously described as a challenge; thus, we interpret a connection between these dimensions since their relevance and perceived value support it. In this sense, participants valued being taught using the podcasts with this perspective as a teaching resource. This idea is related to the fact that the podcasts were on topics about which the participants lacked prior formal preparation. Thus, the topic selection was positive for seeing future connections, i.e.,

> “Something that caught my attention in addition to climate resilience, was the fact that I'm not as familiar with biology and chemistry as my peers [other preservice teachers] obviously are, but (...) now, from the perspective of the climate crisis, earthquakes and tsunamis, I feel them as something much closer, not so abstract, so adding that interdisciplinarity from the point of view that now I, as a physics teacher, can relate to chemists and biologists, is a wonderful thing because now we can make a connection and say that we can approach this (...) from the sciences together! And we can approach it in a way that the children can say yes, there is a relationship, and it is not something that is separate...” (Participant 5).

> “(...) one of the things that most caught my attention [about the podcast] and made me think was that, although each person [podcast guests] was an expert in their own area, they all came up with something, they all talked about something. And despite the fact that, for example, the human rights person may be very external to the hard sciences: mathematics, physics, chemistry, and biology, they contribute something and contribute to the construction of a collective reflection (....) as [another participant] said, not just staying in the corner of hard science, but including other sciences as well, social sciences, human language... things like that” (Participant 2).

Other technical strengths were the possibility of listening to the episodes anywhere and to use them simultaneously with other activities, such as commuting or walking their pets, allowing the listeners to maximize their time for learning. In their words:

> “I liked that they were flexible in the sense that...I travel a lot, I live in [far away] and I travel 4 hours, I can take advantage of that travel time by listening to the podcast. Also, it's something that now with globalisation is available to everyone, it's very common for people to have Spotify” (Participant 10).

The episode's length was adequate for most participants, and the autonomy to decide when they wanted to listen to it was perceived positively. For example,

> “I listen to podcasts and they're usually like an hour and a half long, so I thought I'd have to listen for a long time... And all of a sudden, I played it, and the first one was like 17 minutes long and I thought oh that's so good! Because it's like the perfect thing to listen to for a while, but it's not so long that I have to organise myself to listen to it, I'm really going to listen to it anywhere. I think everyone here has at least 20 minutes of commuting in the day at least” (Participant 7).

> “I'm just getting into the teaching role and the fact that it comes from your initiative makes you a kind of protagonist and you don't expect a grade, you don't expect any benefit other than learning. It happened to me yesterday listening to the podcasts, I did it while walking my dog, so the sense of productivity, which I always fight a lot with, was very good. I'm doing something that keeps me entertained while I'm occupying my time with something very applied and that also fulfils me in other areas” (Participant 13).

Another strength of the podcast, mentioned less frequently by the participants, was its ability to reach a broader audience beyond preservice teachers, given its understandable language and subject matter. As participant 9 stated: “(...) although they are clearly focused on teacher education, in fact anyone who is interested in these topics could listen to it without any problem”. The pedagogical design aligned with sustainable citizenship and the sound design was also highlighted occasionally:

> “I also liked the way they explained the information (...) Because even though I didn't see what they were saying, they were suddenly talking about the phenomenon and the question and the model and I was imagining it in my head, but I felt that it was easy to understand the way they explained it” (Participant 7).

4.5 Elements to be improved

The most frequently mentioned elements to be improved were adding video or a vodcast version of the episodes to expand the formats available and enhance the "closeness" or interaction with the audience. This idea is expressed in the following quote:

> “As a recommendation (...) nowadays podcasts are being used in a more visual way. There is the option of listening to them, but also of watching them (...) as a way of feeling part of it [the podcast], because if you listen to it, and you start tidying up, there are things that are going to get lost, but if you watch it, you also get involved in the conversation” (Participant 1).

Another recommendation involved ending some of the episodes with a more direct conclusion:

> “(...) there was a beginning, a development, but the end of the first podcast was like saying goodbye to the people who were there. But of course, I think it's like a preconception of mine that the conclusion is more for the listener, of course, maybe something more direct (...). The conclusion, if there was one, I didn't really get to listen to it...” (Participant 6).

Minor technical issues such as overlapping voices in some passages and disparate volumes were also mentioned. For example, Participant 9 noted, “the issue of the microphone is very important, that it is heard as relatively similar in all the people who are speaking, because that can sometimes cause some things to be lost”. Another participant noted that the flow of conversation in the first episode could have been improved, “I felt that there were parts of it that were a bit too scripted, like it lacked that fluidity that you get in a podcast that you listen to” (Participant 2).

The less frequently mentioned elements to be improved were the broader dissemination of the podcast on social media platforms, linking it to other interacting instances such as repositories or forums, and shortening its duration. Nonetheless, duration was also mentioned by other participants as a strength, thus, opinions varied.

4.6 Interpretation of the Phenomenon

The core category of this study was **teaching sustainable citizenship**, which was considered a critical area with ambitious aims, challenges, and pedagogical resources. The context of this phenomenon, as perceived by the participants was a challenge, as they did not have personal experience with learning sustainable citizenship in school (as students) or in their teacher education programs. Participants indicated that this

lack of experience as a student was significant in understanding why they felt very challenged, considering they also lacked experience as preservice teachers. The participants faced constraints due to a lack of prior education on sustainability in school. Furthermore, as preservice teachers, they have not received instruction on sustainable citizenship, which is very concerning given that in Chile, this subject has been a compulsory part of the secondary education curriculum since 2020. Thus, they experienced a sense of under preparedness, which created tension. Nonetheless, participants also valued the more flexible teaching methods they believe can be implemented in their future lessons. They viewed podcasts as a suitable tool for diversifying teaching methods in teacher education. These elements are reflected in the following quotations:

> "And especially these courses that are not... We are not being taught sustainable citizenship! In our case, [we have a major in] biology and chemistry. Fortunately, our program has an early practicum. [We observe] an internship, and that is the reason why they put us in any course, and the majority choose sustainable citizenship, as we have had this opportunity" (Participant 1).

> "Just as an idea (...) to highlight the topic of podcasts, in our [teacher] education, we are always told about the need for teaching methods diversification for the pupils, but in our own [teacher] education, the way we learn is scarcely diverse! So, using resources such as these podcasts for our [teacher] education, I think is also very wise" (Participant 12).

Considering the intersections between the study objectives, as illustrated in Figure 1, some elements mentioned as challenges in teaching for sustainable citizenship were also described as pedagogical resources. One such element is the use of socio-scientific issues, because controversial topics were simultaneously viewed as a challenge and a resource. Likewise, context-based and territory-responsive teaching shared this dual dimension. For instance, the challenge of integrating socio-scientific approaches also had the advantage of revitalising traditional scientific knowledge.

> "The advantage of a socio-scientific approach is that the social part revitalises the knowledge. Of course, I see knowledge in class that is a little more academic than the teacher explains. Still, then later, I see it in the news, when classmates talk about it, when they talk about it on different social networks that I see, you will have this more social aspect that relates the science that I saw in class with this more social aspect that is constantly happening every day, which in turn generates more significant learning about this type of content" (Participant 8).

Lastly, the socio-political dimension of science education was perceived as a resource for teaching sustainable citizenship, which was also seen as one of the strengths of the podcast series.

> "The one with the human rights approach was my favourite [episode] because I was unaware of that. It is a good thing I have not had early practicum because now I am aware that maybe, although it is not in my lesson plan, I can add it anyway, as a human being with integrity who has to educate another human being with integrity (...) I will educate from that perspective now, from environmental awareness" (Participant 1).

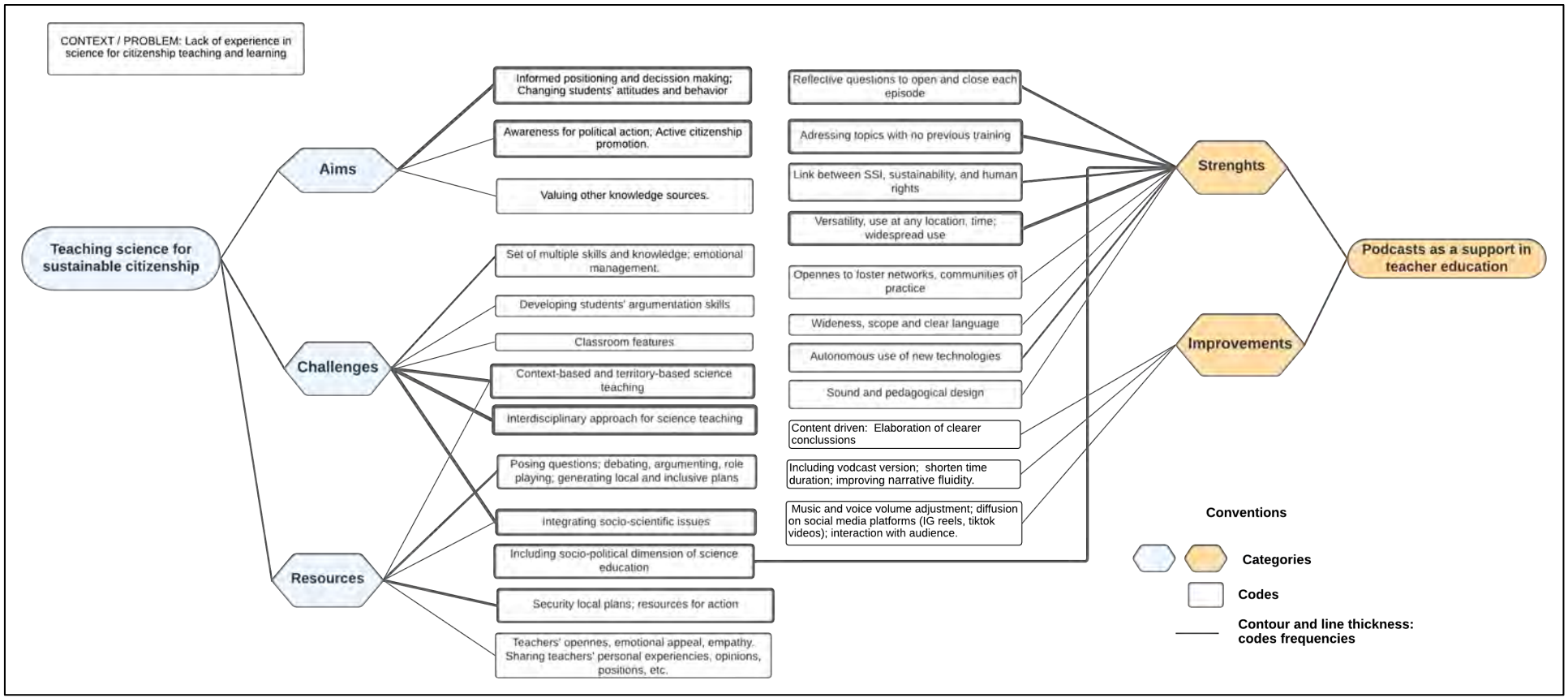

Figure 1. Selective coding of teaching science for sustainable citizenship and the podcast series

5 Discussion

The current study explored the objectives and challenges of teaching science for sustainable citizenship as perceived by preservice teachers, along with assessing the strengths and areas for improvement of a podcast series for sustainable citizenship. The following section interprets these findings in the context of prior research, highlighting implications for science teacher preparation in Chile. Finally, we expand the discussion to an international perspective, proposing new questions regarding the use of podcasts for fostering critical science literacy in teacher education.

The main challenge highlighted in the study emerged from the constraints faced by preservice teachers who must teach in areas where they lack preparation. These challenges include the development of interdisciplinarity in science teaching, integrating the social dimension in socio-scientific issues, and context-responsive teaching. These were related to what participants indicated as key aims in teaching their discipline: the development of students' critical thinking, promoting informed positioning to take action in science-related issues, and context-responsive teaching methods. In the international context, the importance of science teachers at the school level in preparing students for active and participatory citizenship was addressed approximately a decade ago in the "Framework for Science Education for Responsible Citizenship," developed by the European Commission. One of the recommended national actions was to "Develop benchmarking and quality certification of curricular and/or extracurricular programs and outreach activities to provide pathways to higher, vocational and professional science education and training" (European Commission, 2015, p. 29). However, the Eurydice report (2017) indicated that despite the progress made in teacher education and school leadership in citizenship education, significant policy gaps continue to exist across Europe. Similarly, research conducted in South America showed that science education teaching programs struggled to achieve scientific literacy related to inquiry-based instruction (Cofré et al, 2015). Therefore, concerns about science education and its links to citizenship and sustainability have not yet been adequately addressed.

Many teaching resources identified by participants were also related to interdisciplinarity and inquiry-based teaching. Additionally, preservice teachers valued the podcast series created by the research team as a new epistemic and pedagogical tool that can support teacher education goals for sustainable citizenship and the pedagogical strategies they can put into practice, although some technical improvements were also identified. In this sense, the use of podcasts in this study can be considered an

approach oriented toward promoting student reasoning, scientific literacy and deliberation of social issues (Hess & McAvoy, 2015; Wui et al, 2023).

One of the most significant findings of this study was the participants' perspective of 'no turning back' in teaching after analysing the teaching of science and sustainability from a human rights perspective. In this sense, the realisation that everything can be examined within the framework of human rights (Tibbitts, 2017) and that, under this premise, the climate crisis violates environmental human rights is one of the critical insights highlighted by the participants. The participants knew earthquakes and tsunamis could become socio-natural disasters if stakeholders did not consider inequalities in living conditions. This finding becomes significant in initial teacher education as it influences the future teachers' conception of their professional role. Their role is not just to shape critical thinkers in the sciences but also to form citizens who know their rights and responsibilities, enabling them to exercise and defend them.

The idea of enabling citizens to make informed decisions and act accordingly is also relevant in this study. Although its scope is limited (only two teacher education programs), participants shared a vision of science education linked to citizenship education by encouraging their students to act within their spheres, being active participants in their communities, whether physical or virtual. The type of citizen that these future teachers aspire to shape aligns with what Westheimer and Kahne (2004) call a 'participatory citizen'. This means that the actions they envision for their students have an individual rather than collective impact, aiming for active participation rather than social change. Future teachers abstain from using quantitative measures to assess student participation, which aligns with embracing a global citizenship approach (Sant et al., 2018). It suggests that they value diversity, inclusivity, and active participation of all students, regardless of their level of ability or other issues.

Another relevant element to highlight in the connection between science education and civic education is the development of critical thinking. The socio-scientific inquiry-based learning approach (Levinson, 2018) shares a common goal with civic education, which is fostering critical thinking. This approach specifically focuses on skills such as empowering individuals to analyse and integrate information and arguments, evaluate information, generate conclusions, and adopt and maintain positions on public issues. The participants in our study highlighted critical thinking as the most essential aim of teaching for sustainable citizenship, which is in line with other authors who emphasize that one of the primary purposes of science education is to develop students' critical thinking and decision-making skills about crucial issues

(Hogan & O'Flaherty, 2021). They also stated the podcasts' pedagogical design, which integrated reflective questions, facilitated their exploration of the social aspects involved in teaching about the climate crisis, earthquakes, and tsunamis, which we interpret as enhancing their critical thinking. We designed this action research with podcasts to target the third use described in the literature, which is *supplementary* to instruction or learning processes (Heilesen, 2010). However, our study identified a fourth use of podcasts: promoting critical science literacy. In this case, it applied to teacher education. This fourth type of usage was enhanced by the following features: disciplinary integration in the topic discussions, critical perspectives with various interviewees, and a pedagogical structure of questioning which created dialogue between the sciences–chemistry, physics, biology- and social sciences. The podcasts also created anchoring situations simulated by the voices of young teachers to promote identification and emotional connection. The sound design also helped support this purpose by adding a degree of realism.

Among the practical implications, this study presents an example of working with socio-scientific issues in teacher education related with chemistry (climate change) and physics (earthquakes and tsunamis) that can be enriched with disciplinary integration. It is possible to broaden its impact by selecting other complex teaching phenomena and designing materials for teacher education. However, applying this humanistic view to other difficult topics to teach, such as chemistry lessons that are at a microscopic or symbolic level of representations, may have limitations. The proposed strategy could be useful to teach broader ideas; for instance, that chemical activities are dependent on natural resources to produce substances and processes. Furthermore, it can deepen understanding of the social, economic, political, environmental, ecological, and ethical consequences of these processes, as well as that the development, distribution, and consumption of chemicals involves benefits, costs, and risks that must be identified, evaluated, discussed, and clearly communicated to all stakeholders (Talanquer, 2016). On the contrary, when it comes to teaching the particle nature of matter or other challenging topics (Tsaparlis & Sevian, 2013), the strategy proposed in this study may be less applicable for transferring knowledge.

Nonetheless, the pedagogical design of the podcast series presented here shows how citizenship, sciences, and social sciences can be addressed in a complementary manner, with a high potential for integrating different bodies of knowledge in understanding and teaching controversial topics. The participants lauded the interdisciplinary approach taken in the podcast series as a model to replicate in their future

lessons. This was because, by design, the podcasts were engaging, integrated various disciplines, fostered critical reflection through posed questions, and encouraged autonomy in taking a personal perspective. It is particularly relevant for the teacher education system for which this study was conducted because science teachers need to integrate and teach these topics as part of the new curricular course “sciences for citizenship”. The participants have a practical resource to encourage debate in their classrooms and become aware of the complexities of these topics. Podcast series are a low-cost tool they can replicate, share and re-create. This is a practical implication for science teacher preparation in Chile that can be expanded to other contexts.

Our study might also have implications for educational policy, as it addresses the asynchrony between societal learning needs and teacher education. In Chile, the compulsory school curriculum added a teaching area for sustainable citizenship in 2020. However, neither in-service nor preservice teachers have received formal preparation to update their knowledge and practices. Changing teacher education trajectories requires considerable effort and time; therefore, new learning and teaching methodologies can aid in quickly addressing ongoing needs. Likewise, educational podcasts can disseminate academic research with new findings, thus strengthening the links between curriculum, policy, research, and practice. We encourage teacher educators and higher education policymakers to reflect on the responsiveness and relevance of teacher education to the evolving school curriculum.

In critically analysing our study methods, we note two key points. First, the invitations to participate were carefully delivered by the researcher, who was not the participants' teacher educator in the regular teacher education program. This decision was made to avoid social desirability bias in the responses and to respect the voluntary nature of participation in the study, which we consider a methodological success. Second, it is interesting to note that in prior research involving the use of podcasts in education, not all students found this tool helpful (Kazlauskas & Robinson, 2012). Hence, we compared our findings in a different context. We found that the podcast series was valuable for this group of preservice teachers who voluntarily agreed to listen to it. This might have been due to its tailored design, which addressed their perceived learning needs. Indeed, the participants acknowledged its importance in filling a critical gap in their educational trajectory.

Nonetheless, our study participants also highlighted a possible drawback of using podcasts: the potential reduction in interaction with the teacher, as noted by Kay (2012). They mentioned areas for improvement, such as adding videos of the

interviews, which we interpreted as looking for proximity. They also suggested including the podcast in a repository with other teaching materials or opening a forum for interacting. Thus, we agree this format of presenting information could improve interaction possibilities with the audience, facilitating asking questions or networking with other preservice teachers in diverse geographical locations.

Finally, regarding methodological limitations, we completed the group discussions near the end of the academic year, which precluded the initiation of a new wave or the continuation of data collection from other group participants. This means we cannot ensure that complete saturation of all the categories has been reached. We know we could have continuously collected new information because each topic opened a new and deeper area of study. A possible projection is exploring if podcasts could expand citizens' access to resources, especially in zones where scientific literacy about socio-scientific issues is less advanced (Medina-Jerez, 2018). Another avenue to explore is how in-service teachers who are not digital natives might engage in less traditional ways of teaching and learning. Further research could explore this question across various generations of teachers, promoting intergenerational learning and mentoring.

In conclusion, the autonomous use of the podcast series we reported in this study triggered remarkable reflection processes about the human rights perspective in preservice teachers, revealing some of the socio-political dimensions inherent in science education. It promoted personal re-positioning in the group of participants as active citizens and educators, which is crucial for developing critical science literacy in teacher education. This signifies the significant contribution of action research, with the possibility for replication in diverse teacher preparation programs beyond science. It highlights the importance of empowering preservice teachers to autonomously identify and pursue what they need to reshape future classrooms in times of global crisis.

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