

Science communication and outreach with music from plants and phytoacoustics

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ABSTRACT

Integrating innovative methods in scientific communication is essential to stimulate interest in science in particular in children and young people. Music originated from electric conductivity (EC) of plants seems to be an effective tool for translating complex scientific concepts into simple and engaging sensory experiences and to underline the potential of music for sustainability transformation. Plant-generated music, through immersive sound experiences and promoting active learning, makes scientific concepts more accessible stimulating curiosity, motivation and interest in scientific research and environmental issues. Many studies confirmed the effectiveness of non-formal approaches in science dissemination and the experiences made at the Institute for Biological Systems of the National Research Council of Italy (CNR-ISB) highlight how music generated from EC of plants and phytoacoustics may encourage scientific and sustainability awareness and a multidisciplinary vision of natural sciences.

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1. INTRODUCTION

Scientific communication, dissemination and outreach have become a well-established theoretical and operational framework according to many points of view; just consider for example the presence, within the European research projects, of specifically dedicated Work Packages (WP) for communicating and sharing research results also to stimulate interest in the public (especially the young generations) in science, in the implications of scientific research and in the careers in research. The overall idea is to contribute in developing and strengthening scientific culture within society and in stimulating a better informed awareness in public opinion about some issues of particular relevance, such as climate change, biodiversity, environment, health, nutrition and energy [1-8]. Social media and the spread of “open science” are increasingly transforming the concept of science communication and its strategies. We are experiencing an omni-directionality in the communication process caused by the continuing multiplication of platforms with a significant increase in the number of recipients and actors of communication who (not always scientists, science communicators or research facilitators) tend to intervene in the communication flow. Nonetheless, the role and function of influencers and the fact that scientific topics are shared and debated on Twitter or Facebook cannot be ignored [9-14]. Interactivity, real-time information exchange, users, social networks and online media, an extremely fluid concept of public audience, etc. drive to a re-thinking of the models at the base of scientific knowledge transmission. The model of unidirectional information transfer based on a unilateral (top-down) relationship between communicator and receiver(s) appears particularly inadequate mainly in case of face-to-face initiatives with little or no audience involvement. The continuing evolving of social and technological context of information, together with the related modifications in mentalities,

visions, languages, attitudes, behaviours and in the capacities and possibilities of adaptation of the audience of recipients, have to be taken into proper consideration: the alternative is to reduce science communication to a boring monologue rather than a dialogue between interest groups and differentiated components of an extremely articulated audience.

These premises highlight the complexity of managing science communication encompassing some critical factors in terms of quality and quantity of verbal and non-verbal communication, involvement, the specific characteristics of the audience being more or less informed or more or less capable in receiving the messages of scientific communication.

Two critical variables can highly influence these processes:

- the audience level of interest in science;
- the audience capability in understanding science.

These two variables can act simultaneously but at very different levels: a given group can show a high level of interest in some scientific topics but with a very limited level in understanding science contents or viceversa. Communicating and disseminating science often imply the presence of this fluid and rather “unstable” scenario particularly in case of live events for a non-specialist audience. This instability can be even more amplified when dealing with younger generations because they are more exposed to sources of information often of dubious quality (different from the mainstream media); moreover, they require particularly engaging initiatives based on “their” language and their “attention curves”. Scientific dissemination to young audiences involves aspects related to the topics being communicated, the methods of communication and to the tools of communication. Young people use decidedly fast and less conventional tools and languages, they have different communication times and speeds, and different attitudes and relational approaches to science thus requiring specific strategies and approaches to create and maintain adequate levels of involvement, attention, interest and participation, particularly responsive to react promptly to the mood of the participants.

2. ATTRACTING ATTENTION: MUSIC AND SCIENCE OUTREACH

When communicating science in particular to students, language is a particularly sensitive issue. Youth language can be identified by several characteristics [15-17], for example by its morphology, the use of Anglicisms and the influence of different domains such as media, fashion or sports and, not secondarily, music. The adoption of a not “too scientific” language, the recourse to appealing and clear vivid examples, using not too formal contexts, etc. can contribute to reduce the gap between “knowledge authorities” (or perceived as such) and the target group, between communicator and audience, even in virtual contexts [18], to create and stimulate interest (a state of curiosity and engagement with a particular subject or activity) and to attract and maintain attention (the act of focusing on specific information while ignoring other distractions within a given time course) in the audience. These two interrelated dimensions are essential in encouraging social interactions and human cognition at the base of any process of science communication preparing the ground for learning, developing the ability to understand each other and facilitating communication itself. The presence of some “competitors” may act as “alternative attention attractors” (distraction agents) creating forms of dis-attention. Television and video games are typical distractors but the smartphone, and its frequent obsessive use, today surely plays a critical role. Nowadays, among young people and students the dependence to these devices is quite evident and the use of smartphones is ubiquitous: they spend a lot of time online being the majority of people exposed to the online environment. Smartphones are usually connected to the Internet most of the time: it allows students to perform multiple activities and tasks easily, such as checking emails, surfing the web and sending tweets and messages via social networks but many features of these devices have been designed primarily for entertainment and pleasure purposes. This is the reason why smartphones are seen as distractions in the classroom rather than as learning tools [19-22].

This technology, with its pervasive acceptance and powerful functionality, has inevitably changed people’s behaviour, language and the ways of capturing attention. In the classroom or during outreach events, students pay more attention to what it is happening on the smartphone than to their peers or teachers: they can easily be distracted by video and entertainment applications, incoming phone calls or messages from social networks and apps. The distraction potential of a smartphone (and

its capability also in delaying and altering the learning process) is essentially based on its simple use, speed, massive presence of entertainment apps (watching videos, playing games) [23]. These technologies are totally inspired by the concept of speed, involvement, little effort; conversely, lessons, seminars, tools and learning processes depend on definitively slower and more laborious processes requiring higher mental resources consuming efforts. The conflict resulting by these two diverging dimensions can fuel, if not adequately managed, serious problems in terms of attention management (Figure 1).

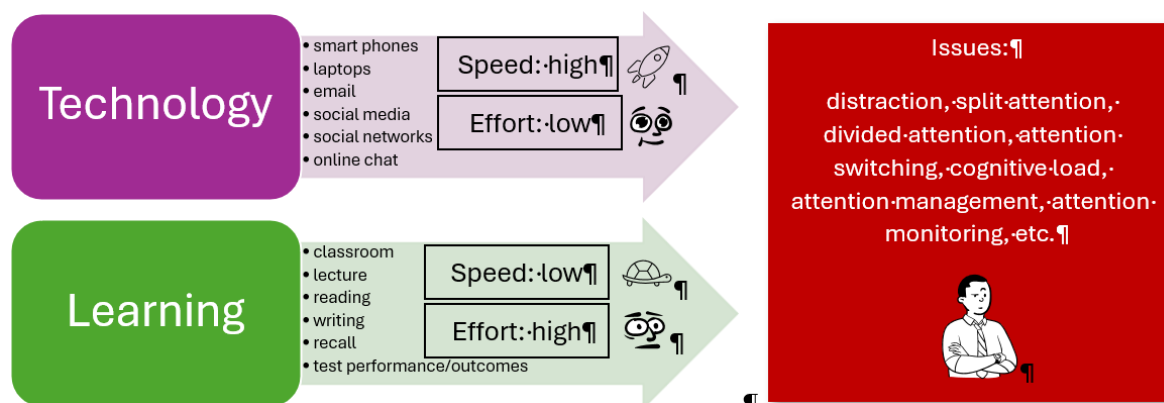


Figure 1. The conflicting divergence between technologies and learning.

Informal science education activities can therefore represent an alternative approach to integrate formal education and increase the general levels of engagement in science learning [24]. Furthermore, they can have stronger impacts on future academic career choices among students [25] and activate very positive changes in students' opinions, visions and perceptions about science and scientists. Moving from STEM (Science, Technology, Engineering, Mathematics) to STEAM including arts (Science, Technology, Engineering, Art, Mathematics), is at present considered a strategy to empower learning processes. Although there is not a clear consensus about the effectiveness of STEAM as well as on how to effectively balance artistic and STEM content [26-28], this approach is gaining interest as useful tool to stimulating the “outside-the-box thinking” [29] at the base of the creative and innovative processes. Within STEAM activities, music is likely to be a positive component to attract attention of an audience composed of young students to stay in tune with them and to promote the so-called informal learning. Music has presently gained a peculiar role among the different possible integrated ways to connect STEM and the arts to communicate specific STEM contents, to make STEM contents more accessible and to increase students' involvement in the learning process [30-34].

Music can become a particularly efficient and positive vehicle for science communication and dissemination: it is a fun way [35-37] to involve students in STEM subjects such as biology [38-40], chemistry [41, 42], computer science [43, 44], mathematics [45, 46], physics [47, 48] and statistics [49]. Music easily focuses the attention of adolescents also because it can be in tune with their culture and fashions [50-52] as for example in the case of the use of hip-hop or techno sounds [53, 54]. In addition, when directly involving students in the processes of composing and creating original music related to STEAM [55, 56], rather than being passively subjected to it, the impact of music on the processing and/or assimilation of content could be particularly profound also helping to develop a more holistic view of science than traditional lessons.

3. MUSIC, ENVIRONMENTAL EDUCATION AND ECOLOGICAL LISTENING: INTERDISCIPLINARY PERSPECTIVE

Contemporary environmental crises, characterized by biodiversity loss, climate change, and ecosystem degradation, are compelling scholars and educators to reconsider traditional modalities of science and environmental communication and education. Among various communicative tools, music has emerged as an useful tool for conveying urgent ecological messages, capable of transcending

linguistic, cultural, and demographic boundaries. The United Nations Environment Programme (2016) highlights music's unique capacity as "one of the most effective means of communicating environmental messages to billions of people around the world, regardless of race, religion, income, gender or age." Despite this acknowledgement a major focus still remains directed on the visual arts, particularly within STEAM frameworks, while music and sound-based initiatives remain comparatively marginalized [57]. The integration of music and environmental education in formal pedagogical settings is likely to be rather limited, with relatively few curricular models that explicitly activate auditory and multisensory engagement [58]. The sonic dimension of environmental education, including soundscape ecology and eco-acoustics, has only recently begun to gain scholarly attention [59-62]. A relevant aspect for expanding environmental music education lies in transcending an anthropocentric focus on human-generated (anthropophonic) sounds to incorporate biophony (the acoustic signatures of flora and fauna) and geophony (non-biological natural sounds such as wind, water, and geological phenomena) [63]. The convergence of sound studies and ecological inquiry has given rise to disciplines such as eco-acoustics, which investigates environmental systems through sound [64, 65]. Unlike bioacoustics - which focuses primarily on animal communication - eco-acoustics considers sound to be both a component and an indicator of ecological processes. The interdisciplinary field of eco-acoustics, distinct from but complementary to bioacoustics, examines ecological patterns and processes through sounds, considering acoustic signals as integral components and indicators of ecosystem health. Soundscape ecology further synthesizes approaches from bioacoustics, landscape ecology, environmental engineering, and social sciences to interrogate interactions among biological, geophysical, and anthropogenic sound sources. Active listening becomes a critical competence for overcoming "environmental deafness" and cultivating ecological literacy, thereby fostering deeper environmental stewardship. Active listening, as intentional and receptive attentiveness to soundscapes, enables individuals to approach environments as complex acoustic entities that embody place-specific ecological and cultural meanings contributing to a shift from "music education" to "sound education" to create the conditions for a more inclusive framework that cultivates relational awareness across human and non-human ecologies.

4. PHYTOACOUSTICS, PLANT BIOACOUSTICS AND ELECTRICAL CONDUCTIVITY IN PLANTS

The terms "Phytoacoustics" or "Plant Bioacoustics" describe the relationships between plants, trees but also fungi and sounds: they include the modalities through which plants perceive and respond to sounds and vibrations, the possibility that plants respond to natural sound sources from the surrounding environment as well as to music or any artificial sound [66-70]. Some studies are exploring the way in which plants produce sound waves creating a very fascinating topic even for the general public, considering that plants or trees do not have specialized organs for "hearing" or generating sounds. The question of acoustic detection and sound emission in plants has been a subject of controversial studies and debates for a long time [71-73]. Given the characteristics of this peculiar scientific area, research is focused in producing new experimental evidence to verify the role of acoustics in plant behaviour. How plants, trees and fungi produce this sound activity is still unknown, but research is evidencing that plants emit sound being also able to hear them.

Another approach somehow linking plants with the sound dimension is based on the detection of the electrical activity of a plant, capturing its electrical conductivity (EC) [74-76]. EC is translated into audio signals that can in turn be transformed into sounds and musical notes thanks to a synthesizer. These audio devices, transforming a plant bio-electromagnetic activity, render plant EC impulses an audible experience.

Phytoacoustics can become a powerful tool for scientific outreach and environmental education. The idea of being able to "listen" to a plant—not in a symbolic sense, but in a real one—opens up impactful possibilities in both educational and artistic contexts. Educational experiences based on the active listening of sound ecosystems and plants, encourage an embodied and multisensory participation, where sound is not merely an aesthetic medium but an ecological language that connects humans and the environment.

These considerations have represented the premises for a discussion in our science outreach team for the identification of new approaches and strategies for a more efficient scientific

communication through practices capable to offer a new model of engagement: not simply transmitting information in a one-way manner, but activating experiences that invite the public, in particular young students, to develop an emotional and embodied ecological literacy. Within this theoretical and empirical framework, at the Institute for Biological Systems (ISB) of the National Research Council of Italy (CNR), presentations and initiatives based on some peculiar aspects of Plant Bioacoustics are adopted to communicate not only “what a plant does”, but also the implications of a relationship with a plant through sound. These initiatives are directed to create sound installations and musical immersive performances within an integrated communication strategy to approach nature and plants in a more attractive way and to raise awareness among the general public (in particular the younger generations) on the issues of sustainability, climate change and biodiversity.

At the CNR-ISB several educational, science communication and dissemination events and workshops have been designed and implemented on the base of phytoacoustics during which the electrical conductivity (EC) of a plant has been used to generate impulses being transformed into acoustic signals then processed with a synthesizer. The adoption of devices capable of transforming the impulses deriving from the electrical conductivity of a plant or a tree into audio signals allows the creation of musical performances implementing filters, timbres and sounds of a synthesizer. This electronic musical instrument may generate particularly creative sounds making these impulses extremely evocative. In these musical performances a plant, through its “invisible hands”, can effectively play a keyboard. It is however important to point out that in these activities we are not dealing with “sounds of the plants”, “plant sounds” or “plant music” but rather (and more precisely and correctly) with “sounds from plants” or “music from plants”.

A plant EC is influenced by a very large number of variables: exposure to light with the presence of natural or artificial light, humidity, temperature, presence of parasites, soil quality, etc. Each plant is likely to show its own specific “musical attitude” also according to species, individuals and health conditions. This leads to the creation of “generative music” which always evolves and never repeats itself exactly in the same way. All these aspects are described during the seminar part of the events then illustrated and highlighted by the sound reactions of the plant. This introduction is an essential step to familiarise with the topics and inspire in the audience a sonic relation with a plant and to explain the characteristics of the modular synthesisers capable to create, through electronic patterns of sounds developed by humans, live sounds based on electrical bio-signals emitted by plants. The choice of the notes and keys (also in terms of octave, length, sustain, etc.) varies according to the continuing plant EC variations (resulting from chemical, physical, tactile, electrical stimuli): this condition creates these quite fuzzy “green melodies” producing a bizarre “random” effect. Demonstration events can be arranged showing how generate sounds, melodies and music from a plant or a tree and organize complex “interspecies” musical performances in which human musicians (not only professionals but also students themselves) can play improvisation music executions together with plants. These initiatives are focused on the idea of linking together the listening and learning dimensions to engage the audience, with sonification and audio information expression, for a better understanding science messages and rethinking of our relations with the natural world.

5. A PHYTOACOUSTICS PRESENTATION AND ITS WORKFLOW

Phytoacoustics initiatives are carried out thanks to a small portable phytoacoustics lab composed of the following devices:

- A biofeedback detector with electrodes
- A synthesizer
- An audio mixer
- A groove box
- A converter from CV signals to MIDI signals
- One or two active speakers

The biofeedback device detects the electrical conductivity of the plant through two capacitive electrodes usually applied to the leaves, transforming the electrical impulses into an audio signal. Through its Control Voltage (CV) and GATE outputs, the biofeedback device is connected to the Control Voltage (CV) and GATE inputs in the synthesizer. CV is an analog voltage signal that controls a parameter of a module in a synthesizer while GATE is a digital signal that indicates the

presence or absence of a signal (it's essentially an on/off switch). Through these inputs a synthesizer receive audio signals from the biofeedback device which can be processed through various types of analog or digital sound synthesis modules: for example, through the ADSR envelopes (Attack, Decay, Sustain and Release), filters, different waveforms, low frequency oscillators (LFO), cutoff and resonance, white noise, delays, reverb, etc., it is possible to enhance a raw audio signal with a particular and highly effective sound that can be used to emphasize certain specific aspects of the demonstration and sound performance. A similar workflow can be adopted using a groovebox. A groovebox is a standalone music production tool equipped with a mixer that combines integrated sequencing tools with one or more sound generation modules, most commonly drums, synth bass/keyboards or samples. Using a CV/GATE to MIDI (Musical Instrument Digital Interface) converter, where MIDI (Musical Instrument Digital Interface) is a standard technological protocol that allows electronic musical instruments, computers and other devices to communicate with one another, it is possible to connect the biofeedback device to the groovebox thus allowing the plant to play sampled sounds of piano, saxophone, etc. as well as human voices (Figure 2).

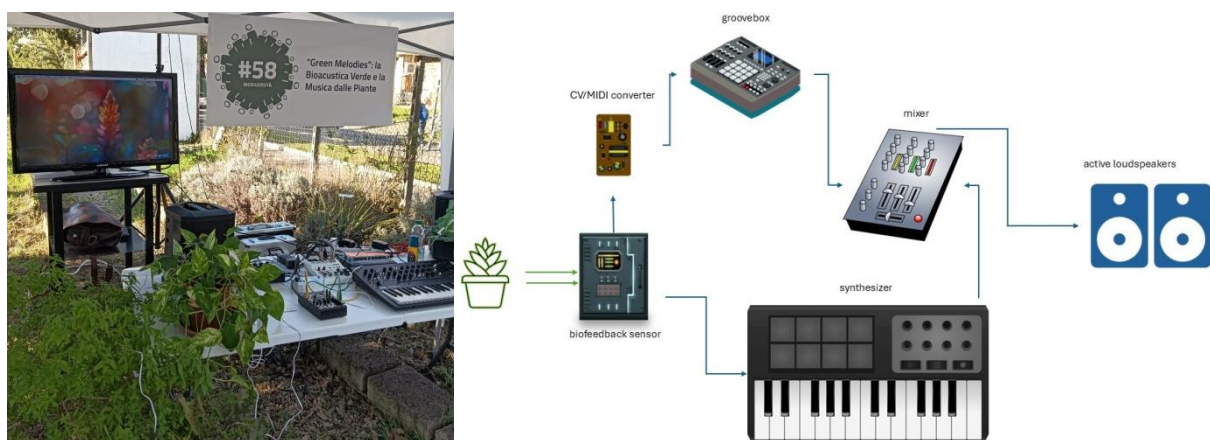


Figure 2. The phytoacoustics lab and its workflow.

The groovebox, appropriately and previously programmed, allows also to perform musical bases with a drum line (acoustic/electronic, percussion), bass, digital synthesizers, samples, loops and many effects: a plant, whether connected to the analogue synthesizer or directly to the groovebox, can play music within an even quite complex song. The creation, composition and arrangement of these musical bases depends on the type of audience: for example, in the presence of young students, techno, hip hop or conceptronics style is usually preferred. Conceptronics can be defined as an expression of experimental electronic style of music, rather than a genre as such, essentially performed and focused on defined artistic operations and contexts such as science fairs, expositions in museums or art galleries.

With this configuration it is possible to create original interspecies performances for example during science festivals always introduced by a short descriptive presentation to illustrate how the phytoacoustics lab works. Thereafter a first demonstration renders a raw signal from the biofeedback sensor audible to the audience. This first type of audio signal is substantially an “inexpressive” and fuzzy sound being based on basic sound of the synthesizer oscillators without any filter and effect. To show the difference with a living plant, the same test is implemented on a plastic plant which cannot generate any sound.

The same audio signal is then passed into the biofeedback sensor capable of “reading” and interpreting the small fluctuations for example in the leaves conductance by stimulating the control voltage and the changes in the gate signal: the voltage variations become variations in the musical notes. These electrodes, through the bio-feedback device, allow the interrelation between a plant and the electronic music player making also possible the recognition and significance of a plant as individual living being thanks to a deeper sense of empathy in the audience. As already mentioned, the electrical conductivity (EC) of a plant is influenced by a large number of variables. This means that through these biofeedback measurements it is also possible to “listen” to the sound of a plant in

relation to its conditions. Potentially, this could be a useful alternative method to have an audio feedback about the “health” of a plant in order to adopt preventive measures before the first visual symptoms of stress appearing on plants. In short, waveforms and music could provide, in a very broad extent, a sonic representation of behavioral patterns of the plant. In our institute we are undertaking some preliminary steps about these phytoacoustics topics we hope to be able to analyse in the near future.

6. DISCUSSION

The main objective of these communication and outreach activities is to involve the audience (i.e. young students) into the topics of scientific research with particular attention to the “green” world, sustainability, the issues of climate change and environmental pollution. These activities are aimed at stimulating curiosity and the “desire to know” as main driver for creativity with an intersection of science theory, biology, ecology and electronic music. Children and teenagers usually show interest in these initiatives especially when music performances are planned and developed using sounds and styles reflecting their musical tastes: all this increases curiosity and interest having also a remarkable positive impact on science communication initiatives. Empirical evidence shows that this approach is likely to be an alternative, more direct and engaging (and certainly less academic and scholastic) method to integrate conventional science dissemination and communication activities (even in case of rather complex topics). These performances have also revealed positive feedbacks in audience also when included to integrate scientific conferences, congresses and seminars, exhibitions and presentations, for the creation of multimedia material as well as specific initiatives and projects that combine science with music and art (Art&Science).

Planning and implementing these events has provided the occasion to reflect about the effectiveness of the traditional format in conventional expositions and presentations, focused on a “monologue” approach [77, 78]. It usually implies a speaker, with its monologue, in front of an audience having a passive role as a simple recipient of information. No feedback about audience interest and understanding or the attention level is considered. Nonetheless evaluating the real impact of this type of initiatives related to phytoacoustics is a complex task. Submitting questionnaires for example to students quite rarely appeared as a viable option because compiling a list of questions is not considered a particularly stimulating and engaging activity. The submission of traditional questionnaires was replaced by direct observations carried out by a collaborator (the observer) placed in the audience. The levels of attention have been detected not using the students' own assessments, but rather through the critical consideration of an external independent observer, whose main task was to note and record the class perception of interest and engagement as well as loss of attention, boredom, distraction and lack of interest, the overall communication quality and involvement potential of the presentation. The number of questions asked during and after the presentation or how often the audience uses their cell phones, whether the questions asked during the presentation actually stimulate discussion, are measured. The use cell phones with a certain frequency by students, has been considered symptom of a decline in attention and interest. Even if based on obviously subjective considerations, the final report of the observer, reporting the class main characteristics and composition, has become however a critical tool not for statistical purposes but rather for corrective measures to improve the next future activities (Table 1). Using music from plants as a way of communicating science is now playing the role of active learning modality among the dissemination and outreach activities of our institute where students can become active participants with greater engagement [79-81]. Science education traditionally presents science in a way disconnected from lived experience, but music seems to solve this gap by helping students in building personal connections with science. They have the opportunity to interact during the presentation by playing along with the plant or checking the plant's reactions, for example, when touched: these events can contribute to involve students in “live” experiences situation and even stimulate their imagination. The identification of the correct and suitable music genre, the appropriate arrangement of the room, organizing small groups of students (to facilitate direct involvement), the possibility to give the opportunity to easily see the plants with the electrodes, the equipment (in particular: synth and mixer), etc. increase the level of entertainment that greatly simplifies scientific communication and dissemination towards young people. This study highlighted how students' non-scientific interests (in

this case, music) can be utilized to support their commitment to science. Interest in music is likely to have a significant educational power for science communication among the young and the opportunity to combine music, electronics, aesthetics considerations (sound, musical instruments, sound design, etc.) may facilitate the expression of scientific information. Our interest in using plant-generated sounds to communicate scientific concepts is inspired by the possibility of transmitting and communicating scientific information in a simple and enjoyable way encouraging people to continue their scientific education. Science is basically a visual field of knowledge: however, sounds can become a particular experience and a peculiar way to integrate and stimulate learning [82, 83].

Table 1. The observer report.

AUDIENCE	Level		
	Low	Medium	High
Chatting during the presentation		√	
Using smartphone		√	
Number of questions during the presentation			√
Relevance of questions during the presentation			√
Number of questions after the presentation		√	
Relevance of questions after the presentation			√
Overall perceived level of attention			√
Presence of period of attention decrease	√		
Overall involvement			√
Overall interest			√
When?	During mid-presentation (technical explanation)		
Time length and frequency of periods of attention decrease	Short (~3–5 min), occurred twice		
SPEAKER	Level		
	Low	Medium	High
Presentation clarity			√
Speech fluidity			√
Use of appropriate terms		√	
Comprehensibility			√
Suitability and adequacy of music			√
Music and sound appreciation			√
Appropriateness of the sound adopted			√

7. CONCLUDING COMMENTS

Many phytoacoustics activities, at the base of the present study, have been included in science communication and outreach events such as various editions of the European Researchers' Night, Science Festivals, seminars, conferences and Arts&Science events. A relevant number of initiatives has involved students based on specific agreements and conventions with schools at various levels and degrees as well as ad hoc programs, promoted by public bodies, involving educational, training and cultural proposals for adults and students.

The present paper has offered an occasion to reflect about meanings, implications and impact of the adoption of phytoacoustics and music from plants among the strategies for the communication of science, dissemination and outreach initiatives of our Institute. In particular, the phytoacoustics initiatives are representing interesting experiences during which the audience can explore a different sensory approach to science communication through sounds providing also positive insights about the complexity of the green world and improving ecological awareness in this era of climate change.

The public in general, and adolescents in particular, are likely to positively welcome these events creating a sort of immersive sonic environments and soundscapes, as concrete alternatives or complements to traditional presentations based on visualization techniques.

Embracing music and sound as integral components of science communication offers a rich, underutilized pathway to deepen affective, cognitive, and sensory connections with the natural world. By expanding pedagogical approaches beyond traditional visual modalities and fostering a relational sound-based ecology, educators and researchers can enhance environmental awareness, foster pro-environmental behaviors, and contribute meaningfully to sustainability discourse. By integrating

music into climate action campaigns, educational programs, and community engagement initiatives, we can tap into emotional and cognitive motivators of human behavior, fostering a deeper connection to environmental concerns and inspiring positive changes.

Learning through music allows students to develop an interdisciplinary lens and enhances their critical thinking skills with respect to academia. Incorporating music with science education not only exposes students to the musical field but also encourages cross-disciplinary learning from a young age. Our initiatives of music from plants with students confirm the potential of music for sustainability transformation because music as experience is likely to show phenomenological qualities that may stimulate biophilia.

In conclusion, it is important to emphasize the empirical nature of this paper pointing to some operational “in progress” considerations for those concretely concerned with science and sustainability communication in particular toward students. The present considerations are essentially made on the author’s practical experiences and reflections: any observation, remark, comment and criticism about these visions and opinions is thus welcome.

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