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Physics of Sound to Raise Awareness for Sustainable Development Goals in the Context of STEM Hands-On Activities

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Abstract: This paper aims to present an interdisciplinary approach intended to raise awareness for Sustainable Development Goals in the context of STEM (Science, Technology, Engineering, and Mathematics) hands-on activities targeted to elementary and secondary school. In particular, contents related to the physics of sound are used to warn about the dangers of noise pollution and its consequences for health, well-being, and productivity. Therefore, it is crucial to inform and raise community awareness on this issue, as well as on the measures needed to prevent its consequences. This research is inserted in a broader pedagogical project that includes primary school and secondary school teachers' professional development and visits to schools to perform several hands-on activities in class aiming to provide students with 21st-century skills related to STEM education. Based on the literature, questionnaires, and participant observation, an empirical study was conducted with teachers who participated in a professional development programme. It is concluded that teachers and students understood the dangers of noise pollution and the measures to be taken to prevent them. Therefore, higher education institutions have a crucial role in the community, namely, through partnerships with schools and teachers' training centres to raise awareness and disseminate and increase Sustainable Development practices in the community.

Keywords: education for sustainable development; sound physics; noise pollution; hands-on; STEM education

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1. Introduction

The Sustainable Development Goals of the United Nations 2030 Agenda were defined with the aim of providing better living conditions for our planet [1]. In this context, there is a need for developing initiatives and activities to raise awareness to achieve the 17 proposed goals, which requires collaboration between countries and several stakeholders such as companies, local governments, regional and international organisations, and civil society, among others [2,3].

This paper aims to raise awareness for SDGs (Sustainable Development Goals) in the context of the physics of sound, namely, by warning about the dangers of noise pollution and its consequences for health and well-being in industrial, educational, or environmental areas. Environmental noise is a form of pollution that can have serious health consequences for populations repeatedly subjected to this exposure [4–8]. For example, in addition to causing hearing loss over time, it can also provoke high blood pressure and stress, which affects well-being and productivity [9,10].

Therefore, it is necessary to monitor sound levels in the environment to check if these are within the safety standards. In this regard, municipalities and other organisations monitor their communities to find out if the recommended values are being met and if there is a need for measures to ensure that the recommended values are not exceeded [11–13].

In this context, several aspects need to be taken into account, in particular noise pollution, including noise impacts such as annoyance, sleep disturbance, blood pressure, and related illness, mental health, or even the reduction of quiet areas, in order to identify non-healthy behaviours and provide measures to prevent it [14–16].

Given the above, it is crucial to inform and raise community awareness on this issue, as well as on the measures to be taken to prevent the risks associated with noise pollution. In this sense, higher education institutions play a relevant role not only by developing research but also by intervening in the community since they are holders of specialised knowledge that should be placed at the service of society [17,18].

This paper presents an empirical study that involves an interdisciplinary approach related to SDGs in the context of STEM (Science, Technology, Engineering, and Mathematics) education that includes a professional development programme (PDP) for teachers and workshops for students. In particular, content and hands-on activities related to the physics of sound are included to draw attention to this issue and its relationship with the SDGs. In this regard, workshops targeting elementary and secondary school teachers and students were developed. The workshop for teachers aims at providing them with knowledge and skills to develop hands-on practices related to SDGs in this theme and also awakening them to the relevant role they can play in raising awareness as promoters of SDG practices. The workshop for students aims to motivate them to develop SDG practices and disseminate them in the community. In fact, they end up influencing their family and friends, as well as everyone with whom they relate, creating a multiplying effect.

To the authors' knowledge, no similar studies are connected to the relationship between sound and SDGs and the need to increase community awareness of this issue through partnerships with higher education, schools, and teachers' training centres. Therefore, this is an important contribution to the literature concerning intervention projects involving partnerships with the aim of contributing to the SDGs. In this regard, several research questions can be raised:

- Do teachers have the knowledge and motivation to develop SDG practices and raise awareness of the need to prevent noise pollution?
- What are teachers' perceptions about their role and the importance of raising awareness and disseminating SDGs in schools and the community?
- Do students understand the need to take into account the noise level?
- Can collaborative projects have an impact on teachers' knowledge and self-confidence to raise students' awareness of the SDGs and the issues related to noise pollution?

This study is included in a broader project, the Academy of Science, Art, and Heritage (AcademiaCAP, Academia da Ciência, Arte e Património), in a higher education institute in Portugal. Since 2013, the AcademiaCAP (www.academiacap.ipt.pt) has been a pedagogical intervention project targeted to promote STEAM education. The main objective is to provide students with 21st-century skills related to STEM education [19–22]. In this context, several artifacts, prototypes, and hands-on practices are developed by higher education students supervised by higher education teachers to be implemented in schools [23–25]. Besides several STEAM hands-on activities in the community targeted at primary and middle school students, it also fosters teachers' professional development [26,27]. In this regard, partnerships are promoted with municipality organisations, teacher training centres, school clusters, and school libraries, among others. AcademiaCAP develops projects using various sources of support from national and European funds, as well as providing services to various entities such as training centres and municipalities.

The paper is organised as follows. The next section presents the background and context of the study; the methodology is described in Section three; Section four is dedicated to the description of the hands-on experiments related to sound and SDGs; Section five contains data analysis and results, including the analysis of questionnaire responses; Section six discussion of the results from data analysis; and finally, in Section seven, conclusions and future work are presented.

2. SDGs and Physics of Sound

As referred to in the introduction, the 17 SDGs aimed to provide better living conditions for our lives and the planet [1]. In this research, the 3rd and 4th goals are highlighted: "Ensure healthy lives and promote well-being for all at all ages" and "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". All activities of the AcademiaCAP are in line with those goals.

Additionally, one of the targets in the 3rd goal is: "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination". The audio, when intentionally produced by amplifiers and loudspeakers, consumes energy. When it occurs in portable infotainment systems (information and entertainment) like mobile phones, tablets, and laptops (whose use is growing enormously), energy is provided by battery usage. Pollution due to battery production and use is an actual theme due to material extraction pollution because batteries are, ultimately, hazardous waste because of their toxic contents and reactive properties. Consequently, moderate use at moderate levels extends battery life.

The previously pointed SDGs are also related to SDG 11: "Make cities and human settlements inclusive, safe, resilient and sustainable"; and SDG 17: "Strengthen the means of implementation and revitalize the global partnership for sustainable development", among others, like SDG 14 and 15, by calling attention to sound pollution and its consequences. In the current project, for example, a partnership with several stakeholders, such as a teacher training centre, school library, and clusters of schools, was promoted to raise awareness for SDGs and to develop initiatives related to this theme in schools and the community.

The physics of sound is also included in school curricula since the first grades of primary school, reinforcing this, as described in this paper. For this reason, it is one of the topics developed and implemented in the workshops.

One of the questions raised is about noise and its consequences for health and well-being: how to measure and prevent or minimise noise levels?

First, noise must be defined. In the current work, noise is the perturbation that causes concern, affecting people and animals in general, their biorhythm, health, rest, capacity to communicate, etc. Noise, in general, can be defined as an unwanted and/or harmful sound. In an evolution of the concept by Fink [28], ambient noise is "the new second-hand smoke". It causes hearing loss; disruption of sleep and speech communication (that can lead to accidents); cardiovascular diseases, and death due to stress-induced problems.

According to the World Health Organization 2018 report, in Europe, more than 100 million are affected by road traffic noise [13]. In addition, more than 1.6 million healthy years of life are lost as a result of road traffic noise in western Europe alone. Other sources of environmental noise can come from railways, aircraft, wind turbines, or leisure noise. Leisure noise can result from nightclubs, pubs, fitness classes, live sporting events, concerts, live music venues, or listening to loud music through personal listening devices.

Given the growing recognition of the risks posed by noise pollution, there is a need to adopt measures to prevent the population from suffering the consequences of this exposure. Therefore, there are several recommendations for protecting human health from exposure to environmental noise. For example, the World Health Organization presents guidelines that contribute to the 2030 Agenda for Sustainable Development because they can influence urban, transport, and energy policies, among others [13]. These guidelines are recommendations aimed at the policy framework for road traffic noise, railway noise, aircraft noise, wind turbine noise, and leisure noise, rated as either strong or conditional (Table 1). In this context, conditional recommendation level means: "recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. As a result, there is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected, or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply" (World Health Organization, 2018, p. XV) [13].

Table 1. Levels of noise recommended by the World Health Organization 2018 [13].

Type of Noise	Recommended Sound Levels [1]		Strength
	Average Exposure (*L*den)	Night Exposure (*L*night)	
Road traffic	Below 53 dB	Below 45 dB	Strong
Railway	Below 54 dB	Below 44 dB	Strong
Aircraft	Below 45 dB	Below 40 dB	Strong
Wind turbine	Below 45 dB		Conditional
Leisure	Average below 70 dB [2]		Conditional

[1] Noise levels for the day-evening-night period (*L*den) and overnight (*L*night), representing the sound levels resulting from the average contribution of all noise sources, for the all-time, typically over one year. The different levels have penalties for the more sensible periods. [2] Yearly average from all leisure noise sources combined to 70 dB.

Moreover, several guiding principles are proposed (World Health Organization, 2018, p. 105–106) [13]:

- Reduce exposure to noise while conserving quiet areas;
- Promote interventions to reduce exposure to noise and improve health;
- Coordinate approaches to control noise sources and other environmental health risks;
- Inform and involve communities potentially affected by a change in noise exposure.

The literature presents several papers approaching effective noise control measures such as noise mapping, technical, planning, behavioural, and educational solutions, as the work of Oyedepo et al. [29].

It is, therefore, essential to sensitise the population to the dangers of noise pollution and pressure political decision-makers on the importance of complying with legislation to prevent the risks associated with excessive noise. With noise prevention, well-being is improved, as well as the reduction of accidents, which results in better health conditions, higher productivity, and consequently reduced health and labour costs, which is a great social and economic benefit for countries.

3. Methodology

It was in partnership with a teachers' training centre (Training Centre "Os Templários", Tomar, Portugal) that a workshop was prepared to raise awareness for SDGs in the context of the physics of sound for 3 h. In addition, with a partnership with Comunidade Intermunicipal do Médio Tejo (CIMT) and schools, another workshop related to the same theme was implemented with primary school students for 1 h and 30 min. Both workshops were implemented with an inquiry approach, where theoretical content was introduced at the same time as several hands-on practices were developed to illustrate the phenomena/concepts intended to be transmitted to the participants. In this regard, sensory experiments with sound within the framework of the SDGs were promoted, seeking to alert to the dangers of noise pollution while introducing the theme, according to the curriculum of schools. Moreover, it highlighted the importance of promoting sustainable development practices to improve health and well-being. Furthermore, it emphasises the role of each one of us as promoters not only of sustainable practices but also for their dissemination in the community.

This paper uses a mixed methodology with questionnaires applied before and after the workshops and a qualitative and interpretative approach that includes participant observation [30,31]. Participant observation occurred during the workshops with teachers and students, where the authors of this paper were the facilitators. The questionnaires targeted to teachers were developed by the authors in Google Forms and were made available online. On the other hand, the students answered printed questionnaires.

Next subsections describe the workshops targeted to teachers and students as well as the participants in the study and questionnaires applied to teachers and students.

3.1. Workshop Presented to Teachers

The main goal of the workshop targeted to teachers was to raise their awareness about the importance of developing SDG practices, in particular those related to the physics of sound, which is a subject included in school curricula. In this regard, the workshop was organised as follows: (i) introduction to the workshop and filling in the first questionnaire; (ii) raising awareness about the importance of introducing new tools and methodologies to engage students to learn curricula contents; (iii) presentation of the SDGs, in particular, those related to sound; (iv) live demonstration of hands-on experiments related to sound; (v) focus group to discuss and assess teachers' perceptions about this thematic; (vi) filling in the second questionnaire.

A description of the hands-on experiments related to sound will be provided in the next section. The goal of the hands-on experiments was to motivate and prepare teachers to promote this approach with their students and be vehicles of good practices in their schools and communities related to the thematic approaches in the workshop.

3.2. Questionnaires Applied to Teachers

In the questionnaire applied before the workshop, the first questions were about the characterisation of the participants, including their age, the grade level they teach, and their subject matter group. The results of these questions are presented in Tables 2 and 3 from the next sub-session. The following questions of the same questionnaire were about SDGs, and the last questions were related to sound.

Table 2. Age of the teachers who participated in the workshop.

Age Range	≤40	40–50	50–55	55–60	≥60
Frequency	0 (0%)	9 (34.6%)	8 (30.8%)	6 (23.1%)	3 (11.5%)

Table 3. Subject Matter groups and grade levels of the participants in the workshop.

Subject Code [1]	Subject	Level of School	Frequency
100	-	Preschool education	2 (7.7%)
110	Portuguese, Mathematics, Study of the environment	1st cycle of elementary school	9 (34.6%)
230	Mathematics and Natural Sciences	2nd cycle of elementary school	2 (7.7%)
500	Mathematics	3rd cycle of elementary and secondary school	2 (7.7%)
510	Physics and Chemistry	3rd cycle of elementary and secondary school	6 (23.1%)
300, 400, 420, 520, 600	Portuguese, History, Geography, Biology and Geology, Visual Arts	3rd cycle of elementary and secondary school	5 (19.2%)

[1] According to Portuguese Thematic and Scientific Areas classification.

The second questionnaire, applied at the end of the workshop, was intended to assess the evolution of teachers' knowledge and their perceptions about the content taught in the workshop. In particular, the goal was to assess several dimensions such as (i) teachers' knowledge about the SDG and sound; (ii) recognition of the role of schools in developing SD practices; (iii) the role of schools in raising awareness and disseminating SD practices through the community.

Both questionnaires included questions of different types from Open, Multiple choice, and Yes/No options. Most of the questions follow a five-point Likert scale with 1 for "Not at all" and 5 for "Very high". Data analysis and results of both questionnaires are provided in Section 5.

3.3. Participant Teachers

Participants are 26 teachers (24 female and two male teachers) who participated in the workshop and voluntarily answered the questionnaire. The following tables provide information about the age of the teachers, the grade level they teach, and their subject matter group. As shown in Table 2, all teachers are more than 40 years old, and 65.4% are more than 50 years old. Table 3 provides information about the distribution of the teachers by their subject matter groups and the grade level they teach.

As can be seen, in Table 3, most teachers are from the 1st cycle of elementary school (34.6%), and the Physics and Chemistry group of the 3rd cycle of elementary and secondary school (23.1%). In all, teachers from 10 different subject matter groups participated in the workshop.

3.4. Questionnaires Applied to Students

Two questionnaires were applied to students before and after the workshop consisting of the hands-on experiments described in Section 4.

Both questionnaires contained the same questions listed in Section 5. The questions included a set of Open, Multiple choice, and Yes/No options, but also some following a five-point Likert scale with 1 for "Not at all" and 5 for "Very high". Data analysis and results of both questionnaires are provided in Section 5.

3.5. Participant Students

A total of 63 students from primary school (35 girls and 28 boys) participated in the workshop and voluntarily answered the questionnaire. Table 4 provides information about the age of the students. 45.9% of those students are enrolled in the 3rd year, and 54.1% in the 4th year of primary school. Two students did not answer the age question.

Table 4. Age of the students who participated in the workshop.

Age (Years Old)	8	9	10
Frequency	18 (28.6%)	31 (49.2%)	14 (22.2%)

3.6. Data Analysis

The data gathered from the questionnaires were organised and worked out using the Microsoft Excel® spreadsheeting software, version 2206, 64 bit.

IBM SPSS® software package version 26 was used to perform a t-test evaluation of the significance of differences in the mean of Likert's data for direct comparable questions before and after the workshop, considering a confidence level of 95%.

4. Hands-On Experiments Related to Sound and SDGs

"Hands-on" activities are a very effective way of involving the community in activities, in this case, teachers and especially students. Moreover, it promotes interest, attention, and long-lasting memory, which makes it an emerging pedagogy [32,33].

In terms of methodology, first, hands-on experiments were performed with students to make them understand the sound phenomena and its properties; then, in what is called the second part, the effects of noise are addressed to promote awareness of the causes and dangers of noise pollution and relate with actions to address the problem. This "in-class" STEM approach includes hands-on experiments guided by the facilitators, as described in Costa et al. [27].

Teachers are natural vehicles for promoting the dissemination of relevant information; the objective is to make students aware of problems that affect society, promote their engagement in disseminating information and promote solutions to solve these problems in their families and communities in general. Therefore, major efforts in teacher training are taken to help teachers implement these new approaches in their lessons.

The first part: understanding the sound phenomena and its properties, implies that along the presentation, the multiple aspects of sound are presented and experienced. The question "what is sound" (pressure variations and consequent movement in the medium) is raised. In Figure 1a, a loudspeaker is used, so the vibration is "felt" at different frequencies. Figure 1b shows the analogy with the propagation of a wave in a spring.

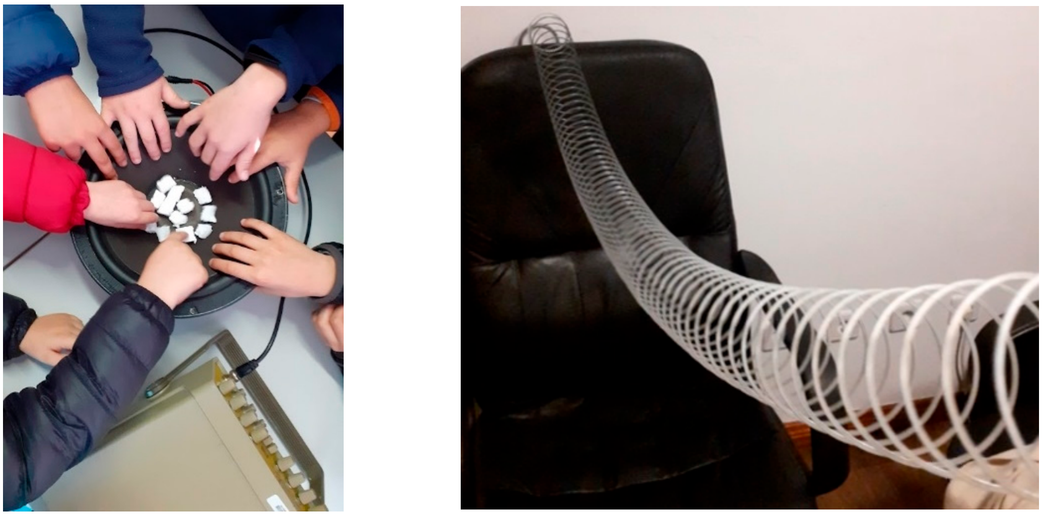

(a) (b)

Figure 1. Relating sound with vibration and wave propagation: by feeling loudspeaker vibration (**a**); and seeing wave propagation in a spring (**b**).

To make the sound waves "visible" and "felt/heard" in the space, standing waves in Chladni Plates (Figure 2a–c) and the school room (Figure 2d) are made at different frequencies. By using sand in the Chladni plates, the waves became visible. When reproducing sinewaves in rooms at one of its acoustic modes, the students can move along it and listen to the different intensities at different places, confirming that there are sound waves in that space.

Then the frequency concept is introduced as the number of oscillations per second, and the frequencies that each animal hears are identified. The upper limit of each student's hearing is tested and related to eventual otitis, noise exposure, etc. Some applications of sound are identified: communication, entertainment, warning, etc.

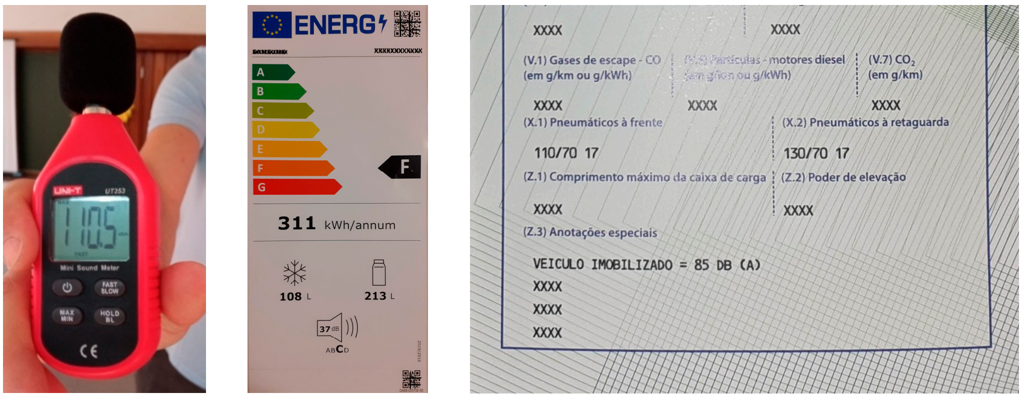

(a) (b) (c)

Figure 2. *Cont.*

(**d**)

Figure 2. "Visualisation" of waves by using standing waves; in solids: (**a**–**c**) Chladni Plates at different frequencies (**a**) 464 Hz; (**b**) 3112 Hz; (**c**) 4310 Hz; and by "feeling/hearing it" by room excitation at different frequencies (**d**).

In the second part, the definition of sound levels in dB is addressed. Using a sound level meter, students are invited to measure environmental noise. By asking them to talk louder and louder, it can be seen that the subsequent sound level gets higher (Figure 3a). At about 85 to 90 dB, the effects provoke hearing loss (other effects are, for example, irritation, stress, vascular problems, not allowing communication, etc.) [5,7,8].



(**a**) (**b**) (**c**)

Figure 3. Concept of sound intensity and measuring it at different levels with a sound level meter (**a**); identification of levels produced by different systems, such as an electric appliance (**b**); and a motor vehicle (**c**).

Methods of limiting production, propagation, and effects of noise are then addressed. Attention is drawn to the fact that there is already an indication of the levels produced through the labelling of household appliances (Figure 3b) or indications in a vehicle's registration booklet (Figure 3c). The propagation speed and applications—echolocation (sonars: bats and dolphins, etc.), are also mentioned.

Attention is also drawn to the existence of digital software tools that can be installed on mobile phones and allow measuring the approximate sound intensity inside and outside the school, thus involving family circles and promoting active and participatory methods.

Some protective measures against noise pollution and its effects are also identified: do not play loud music, and put on protectors when there are high levels of noise. In addition, distance yourself from excessive sound sources, such as music concerts, among other examples.

Because humour and social interaction are also important to promote the willingness to participate and have fun, an electronic system that produces a frequency proportional to the electrical conduction of the human body was also used [34]. This one was built especially for these types of sessions. Students and teachers are invited to test "the sound of your body" (Figure 4), which invariably leads to funny situations.

Figure 4. The joy of discovering and playing: an electronic system that produces a frequency proportional to the human body's electrical conduction.

5. Data Analysis and Results

This section includes two subsections. The first one presents the results of the questionnaires applied to teachers who participated in the PDP. In the second subsection, the results of the questionnaires applied to students during the workshops at schools are provided.

5.1. Results of the Questionnaires Applied to Teachers

The following tables include the questions of the questionnaires applied to teachers before and after the workshop related to SDGs and the physics of sound, and also the main results of the answers to the questions (Tables 5 and 6).

Table 5. Questions of the first questionnaire for teachers (before the workshop).

Label	Question	Type	Main Result	Fig.
Q1_A	Do you know the United Nation Sustainable Development Goals (UN SDG)?	Yes/No	Yes = 61.5 %	–
Q2_A	If you answered yes to the previous question, indicate two or three goals.	Open		–
Q3_A	Have you participated in any PDP related to the SDGs?	Yes/No	No = 96.2 %	
Q4_A	Select the three options that seem most correct to you regarding Sustainable Development (SD): • Economic development; • Ability to create projects that will last in the future; • Environmental issues; • Social issues; • Promoting education; • Better health conditions; • Noise level mappings of population areas.	Multiple choice	6 (15.4%) 13 (50.0%) 24 (92.3%) 12 (46.2%) 19 (73.1% 12 (46.2%) 6 (23.1%)	–

Table 5. *Cont.*

Label	Question	Type	Main Result	Fig.
Q5_A	Quantify on a scale of 1 (Not at all) to 5 (Very high) if you have the confidence and knowledge to introduce this topic to your students.	Likert scale	0% for "Very High" and 9 (53,8%) for High	Figure 5
Q6_A	Quantify on a scale of 1 to 5 if you need professional development in this area.	Likert scale	9 (34,6 %) for Very High and 10 (38,5%) for ≥ "High"	Figure 6
Q7_A	Quantify on a scale of 1 to 5 if you consider that schools should promote SD attitudes and practices.	Likert scale	76.9% for "Very High" and 96.1% for ≥ "High"	Figure 7
Q8_A	Quantify on a scale of 1 to 5 if you consider that schools have a relevant role in promoting SD practices among society in general.	Likert scale	76.9% for "Very High" and 96.1% for ≥ "High"	Figure 7
Q9_A	What is sound?	Open	—	
Q10_A	What is sound for?	Open	—	
Q11_A	Quantify on a scale of 1 to 5 the extent to which you think noise can be dangerous to people's health.	Likert scale	73.1% for "Very High" and 88.5% for ≥ "High"	Figure 8

Table 6. Questions of the second questionnaire for teachers (after the workshop).

Label	Question	Type	Main Result	Fig.
Q1_B	Quantify on a scale from 1 (Not at all) to 5 (Very high) if you have the confidence and knowledge to introduce the topic addressed in the workshop to your students.	Likert scale	14 (52%) for ≥ "High"	Figure 5
Q2_B	Quantify on a scale of 1 to 5 if you need professional development in this area.	Likert scale	17 (68%) for ≥ "High"	Figure 6
Q3_B	Quantify on a scale of 1 to 5 if teachers have a relevant role in sensitizing students to implement SD practices.	Likert scale	76.9% for "Very High" and 96.1 ≥ "High"	Figure 7
Q4_B	What are the main difficulties to develop SD practices (from the next 6 options select 3). • Lack of financial resources; • Lack of information and knowledge; • Lack of human resources; • Lack of time; • Lack of motivation, encouragement, and communication by the leaders; • Resistance to change.	Multiple choice	12 (46.1%) 16 (61,6%) 12 (46.1%) 13 (50.0%) 11 (42.3%) 9 (34.6%)	–
Q5_B	From the following options, select three possible applications of the sound phenomenon: • To communicate; • To make people feel good; • To guide; • To cure diseases; • To prevent possible dangers; • To warn about phenomena; • To calculate distances (echo case, thunderstorms).	Multiple choice	24 (92.3%) 10 (38.5%) 10 (38.5%) 2 (7.7%) 18 (69.2% 10 (38.5%) 10 (38.5%)	–

Table 6. *Cont.*

Label	Question	Type	Main Result	Fig.
Q6_B	Quantify on a scale of 1 to 5 the extent to which you think noise can be dangerous to people's health.	Likert scale	84.6% for "Very High" and 96.1% for ≥ "High"	Figure 8
Q7_B	Do you intend to promote practical hands-on activities related to the theme of the workshop in your school?	Yes/No	Yes = 80.7%	–
Q8_B	If you answered yes to the previous question, give examples.	Open question	–	–
Q9_B	If you answered no to the previous question, explain why.	Open question	–	–
Q10_B	Comments/Suggestions.	Open question	–	–

Select the three options that seem most correct to you regarding Sustainable Development (SD):

First questions of the questionnaires applied before the workshop were related to SDGs, namely, teachers' knowledge regarding this theme (Table 5). Sixteen (61.5%) of the twenty-six teachers answered that they knew the UN SDG (Q1_A), and fourteen gave some examples (Q2_A) as exemplified in the next table (Table 7).

As can be observed in Table 7, from the 17 SDGs, only seven goals were mentioned. Most answers (10 teachers) refer to goal number 1 (No poverty), five to number 2 (Zero Hunger), four to number 12 (Responsible consumption and production), and only two to number 4 (Quality education). Interestingly, one of the main objectives addressed in the workshop, "Good health and well-being", was not mentioned by the teachers.

Table 7. Examples of SDG provided by the answers to question Q2_A.

Goal Number	Goal	Frequency
1	No poverty	10
2	Zero hunger	5
3	Good health and well-being	0
4	Quality education	2
5	Gender equality	2
12	Responsible consumption and production	4
13	Climate action	0
14	Life below water	1
15	Life on land	1
17	Partnerships for the goals	0

Concerning the selection of three from five possible options that seem most correct regarding SDGs (Q4_A), the results are presented in Table 5. All seven options were selected from at least four teachers. Most teachers selected "Environmental issues" (92.3%) followed by "Promoting education" (73.1%), which are, in fact, related to SDGs. "Promoting Education" ranks second, which means that teachers recognise the importance of education in this matter. However, the third most chosen option was "Ability to create projects that will last in the future" (50%), a generic sentence not necessarily related to SDGs. These results show that, although teachers recognise some of the goals, they do not know all of them, and there is still some confusion about this topic. In fact, only one teacher participated in a PDP related to the SDGs (Question Q3_A), meaning they only have common knowledge related to this matter.

Questions Q5_A and Q1_B, respectively, before and after the workshop, are about teachers' confidence and knowledge about introducing the topic of SDGs to students. As shown in Figure 5, no teacher feels "Very high" confidence to introduce SDGs to students before the workshop. In fact, most of them responded that they have "Enough" confidence

(57.7%). Together with the fact that they effectively do not know all the SDGs well, this response is related to some of the goals they think they know about. Therefore, they do not have enough knowledge regarding introducing this topic to students, at least in what concerns all the SDGs, in particular, those approached in the workshop. After the workshops, the teachers' confidence increased to 40% answering "High" and 12% "Very high". This is a slight increase but without statistical significance (from 3.3 ± 0.2 to 3.5 ± 0.4, $p = 0.21$). Because, after the workshop, sound was also included in the activities, this result may be associated with specialised knowledge related to the physics of sound, which can be a challenge for teachers who are not from the Physics and Chemistry group (Table 3). Indeed, some teachers were from groups such as Portuguese or Arts, among others. Therefore, there is a need for more professional development and collaboration with the facilitators for teachers to implement this type of practice.

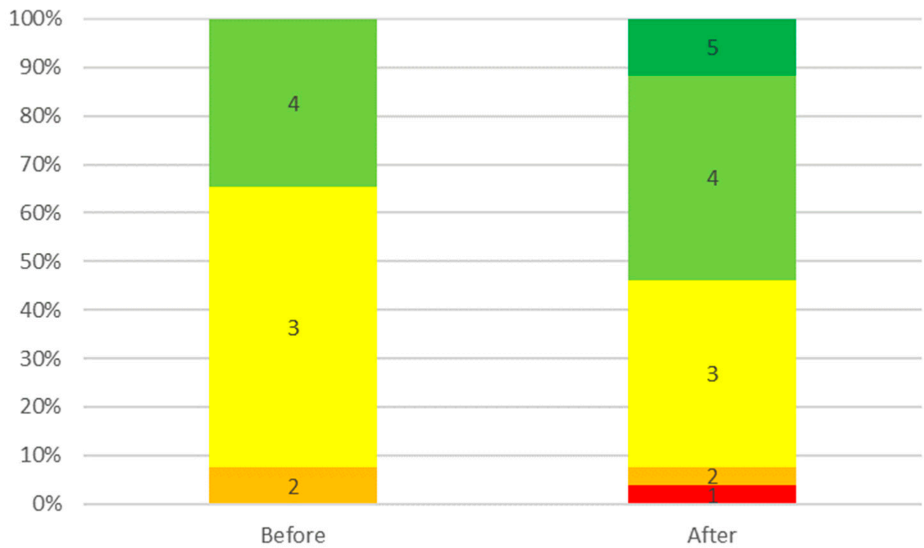


Figure 5. Distribution of answers to questions on confidence and knowledge: Q5_A, before the workshops (left); Q1_B, after the workshop (right). The numbers on the bars represent a five-point Likert's scale.

Regarding question Q6_A, all teachers agree about needing training related to SDGs and sound (Figure 6). This result is consistent with the previous response (Q5_A), where confidence and knowledge to introduce this topic were not high. At the end of the workshop, a similar question was posed (Q2_B), where the results (Figure 6) confirm that teachers recognise the need for obtaining professional development in this matter. In fact, after the workshop, teachers keep finding it important to have training related to SDGs and the physics of sound (the average rankings of 4.1 ± 0.3 and 3.9 ± 0.4, before and after the workshops, respectively, are not significantly different, $p = 0.44$). As referred before, this may have to do, on the one hand, with the specialised knowledge provided in the workshop about the subject matters approached and, on the other hand, with the recognition of the relevance of this theme, which justifies the importance of having training related to it. Again, this justifies the need for an intervention in this area/direction, particularly through teacher professional development.

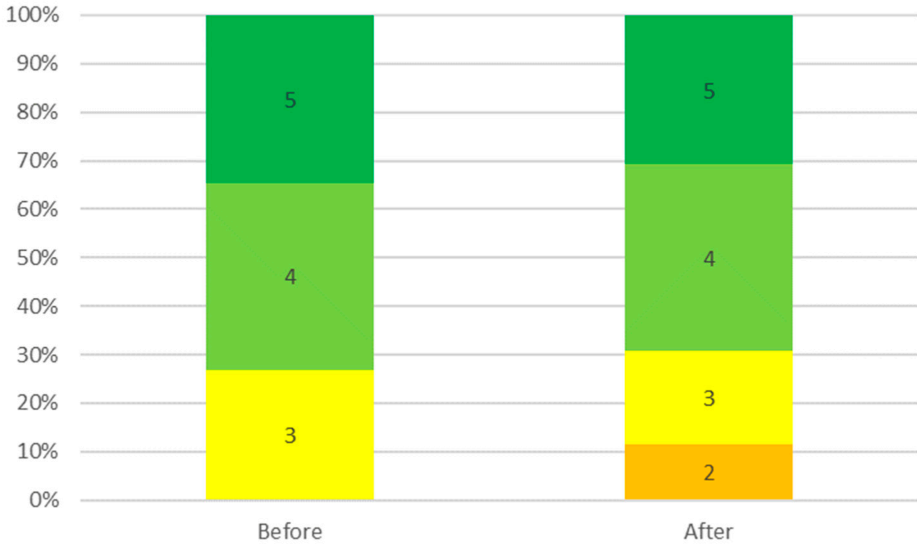


Figure 6. Distribution of answers to questions Q6_A and Q2_B on the need for training before and after the workshop for teachers, respectively. The numbers on the bars represent a five-point Likert's scale.

Regarding question Q7_A, all teachers agree that schools should promote SD attitudes and practices (Figure 7a). Interestingly, the role of schools (Q8_A) is also recognized in relation to promoting SD practices in the surrounding community to the same extent (Figure 7b).

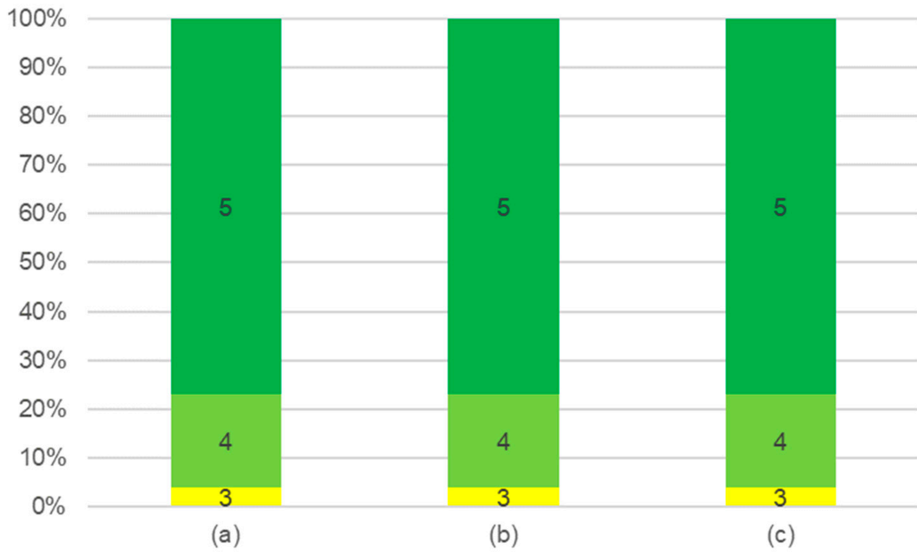


Figure 7. Distribution of answers to questions Q7_A (**a**), Q8_A (**b**), and Q3_B (**c**) on the role of teachers and schools in promoting SD attitudes and practices. The numbers on the bars represent a five-point Likert's scale.

Even more interestingly, after the workshop, the same results were obtained regarding question Q3_B about the role of teachers in sensitising students to implement SD practices (Figure 7c). Therefore, teachers acknowledge the importance of their role and the role of schools in promoting and disseminating SDG practices.

Regarding question Q4_B about the "main difficulties to develop SD practices", teachers had to select three from six options. All six options were selected (Table 6) with a minimum of 32%, which means that teachers consider all options as barriers to developing SD practices. However, "Lack of information and knowledge" was the one with more choices (61.5%). This is an important result that justifies the need for teachers to have professional development in this matter and support in developing this approach in their schools. Therefore, the 4 and 17 SDGs related to "Quality education" and "Partnerships for the goals" are relevant goals regarding efficacy in raising awareness and promoting initiatives related to this theme. Other choices, such as "Lack of time" (46.1%), "Human resources," or leadership, among others, should be related to politics or priorities of school leaders related to projects.

The last questions were more related to the physics of sound. Before the workshop, some teachers gave short answers to question Q9_A: "What is sound?". They made references to vibrations and waves but also referred to the absence of silence or noise that is heard, among others. After the workshop, more complete answers were provided, such as

> *Sound is a wave capable of propagating through the air and other media from the vibration of its molecules. Sounds are perceived by us when they strike our hearing aid, which are translated into electrical stimuli and directed to our brain, which interprets them.*

Regarding the question "What is sound for?", most answers were "To communicate". After the workshop, in what concerns the importance of measuring sound, some answers are provided below:

> *To know its intensity and how to protect ourselves from more damaging sounds.*
>
> *To prevent hearing problems in advance.*
>
> *To study the impact of sound on human life and nature, e.g., to foresee and/or prevent risk situations.*
>
> *It is important because it can affect health and quality of life.*
>
> *To prevent noise pollution.*
>
> *To control harmful noise.*
>
> *To minimize harmful effects on health.*
>
> *To give us information about noise pollution.*
>
> *To safeguard public and individual health.*
>
> *To understand if the sound we usually hear is harmful or not.*
>
> *To understand how many dB it harms human health.*
>
> *As a preventive measure of hearing health at the workplace, warning of the danger of hearing loss.*
>
> *Importance as a means of communication, environmental warning.*
>
> *As a way of ensuring the quality of our health, one of the Sustainable Development Goals of this Millennium.*
>
> *To be aware of the risks to one's health and try to safeguard it.*
>
> *To make students aware of the importance of moderating sounds in everyday life.*
>
> *To determine the decibels to which the human ear is exposed, as noise pollution causes great damage to the population.*
>
> *It is important to measure the sound because noise can be dangerous for people's health.*
>
> *It can cause harm to the population, putting people's health at risk.*

According to the teachers' answers, it can be seen that they have understood the need to measure sound to ensure whether it is within safety standards or whether it is at a dangerous level that can have harmful effects on well-being and health. Furthermore, they mention the relevance of making students "aware of the importance of moderating sounds in everyday life", which is also linked to recognising their role in raising awareness on this issue.

The above perceptions are corroborated by the responses to the following questions, as described below. For example, in question Q5_B (applications of the sound phenomenon from seven options), most teachers selected “To communicate” (92.3%), followed by 69.2%, “To prevent possible dangers” (Table 6). Other answers are related to other dimensions approached in the workshop, such as well-being when listening to music we enjoy and calculating distances (e.g., sensors in a car and the distance of a thunderstorm).

Concerning whether noise can be dangerous to people’s health (Q11_A), only one teacher thinks it is not dangerous before the workshop. In fact, 88.5% of teachers consider it very dangerous (Figure 8). After the workshop, the number of teachers who consider it very dangerous to people’s health increased (96.2%, in Figure 8). However, the difference is not statistically significant (p = 0.50).

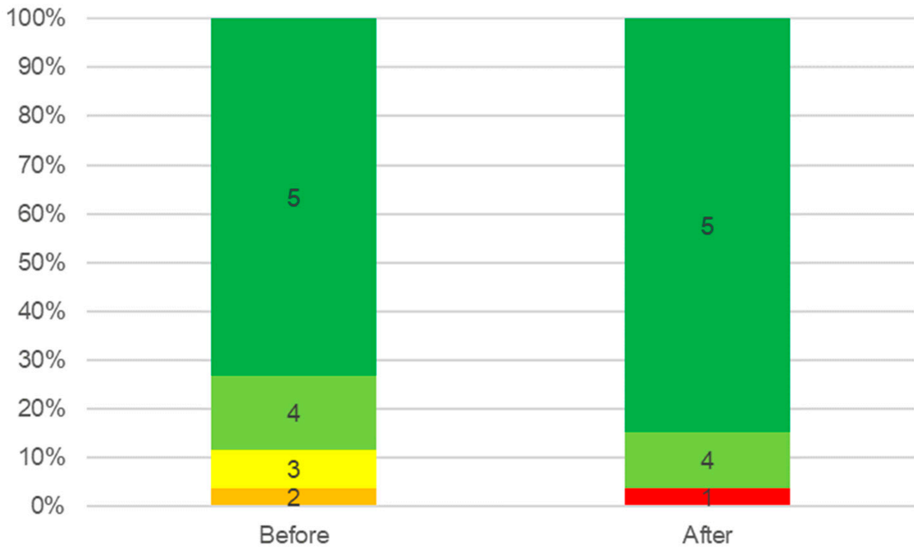


Figure 8. Distribution of teachers’ answers to questions Q11_A and Q6_B on the dangerous effects of sound on people’s health before and after the workshop, respectively. The numbers on the bars represent a five-point Likert’s scale.

Regarding question Q7_B, 21 teachers (80.7%) answered that they intend to promote practical hands-on activities related to the theme of the workshop in their schools (Table 6). This is a good result meaning the workshops motivated them to develop the proposed approach in class. Eighteen teachers who answered “Yes” also gave some examples (Q8_B) as described below:

Using mobile phone applications.

Simple experiments that allow students to understand the sounds that surround them and the effects they can cause.

Practical experiences on the characteristics of sound and practical awareness campaigns, fieldwork, at school for the noise we are subject to in several of its spaces.

Measure the sound level at various locations in the school and more.

Measure the intensity of the sound, according to the exemplified activity.

Noise and sound measurement.

Analysis of information from a household appliance.

Below are some excerpts from the five teachers who answered “No” (Q9_B):

Because I am placed in group 910 (Special education) with 1st-year autistic students and the topic does not fit my current reality.

Without preparation for it . . .

I do not have enough knowledge, because I am a Portuguese teacher.

Based on the above answers, it is verified that teachers did understand the need to measure sound, namely, to identify noise and develop awareness practices to sensitise students and the population to its harmful effects. Indeed, only three teachers answered "No", referring to difficulties related to lack of knowledge.

Finally, regarding observations, at the end of the last questionnaire, some teachers took the initiative to put some sentences, such as

Keep up these trainings!

Thank you for the training. I really enjoyed it!

These practical examples are fundamental for the development of small projects in schools.

5.2. Results of the Questionnaires Applied to Students

Questionnaires with several questions about sound and the SDGs were answered by the students before and after the hands-on experiments presented in the class workshops. Both questionnaires included the same questions (Table 8). The main results obtained are shown in Table 8.

Table 8. Questions and main results of questionnaires answered by students before and after the hands-on experiments.

Label	Question	Type	Main Result	Fig.
Q1_C	What is sound for you?	Open	–	–
Q2_C	Draw a picture of what you think the sound is.	Open	–	–
Q3_C	Do you think it is possible to measure the sound?	Yes/No	Before: Yes = 59% After: Yes = 81%	Figure 9
Q4_C	Do you think sound can bring people well-being and a good mood?	Yes/No	Before: Yes = 70% After: Yes = 61%	Figure 9
Q5_C	Do you think sound can cause discomfort and illness in people?	Yes/No	Before: Yes = 57% After: Yes = 81%	Figure 9
Q6_C	Have you heard of the Sustainable Development Goals?	Yes/No	Before: Yes = 10% After: Yes = 28%	Figure 9
Q7_C	Do you think that sound is related to the SDGs?	Yes/No	Before: Yes = 18% After: Yes = 30%	Figure 9
Q8_C	Quantify on a scale of 1 to 5 to what extent you think noise can be dangerous for people.	Likert scale	Before: 4.0 ± 0.3 After: 4.2 ± 0.2	Figure 10
Q9_C	Quantify on a scale of 1 to 5 in which measures you think the theme of sound is related to people's health.	Likert scale	Before: 2.7 ± 0.3 After: 2.8 ± 0.3	Figure 11
Q10_C	What are the main causes/sources of noise pollution that affect living beings? • Car traffic. • Fire. • Industrial noise: equipment in industries, machinery, saws, etc. • Litter in forests and waterways. • Greenhouse gases. • Misuse of resources leading to waste. • Air pollution. • Domestic noise: sounds of blenders, hoovers, etc. • Noise caused by aircraft taking off and landing near airports. • Daytime entertainment: restaurants, fairs, exhibitions, etc. • Concerts, football matches, or discos. • Discharges of pollutants into watercourses and oceans.	Multiple choice	Industrial noise: Before 16%; After 18%	Figure 12

Table 8. *Cont.*

Label	Question	Type	Main Result	Fig.
Q11_C	From the following topics, select those that may be related to the consequences of sound exposure. • Hearing loss. • Increase in the earth's average temperature (greenhouse effect). • Stress and irritability. • Sunburn. • Effects on the ozone layer. • Low immunity and malaise. • Pollution from gases discharged into the atmosphere. • Headaches. • Death of plants due to pollution. • Lack of concentration. • Decrease of drinking water. • Accidents at work.	Multiple choice	Hearing loss: Before 17%; After 19%	Figure 13

± Represents the uncertainty interval at 96% confidence level.

Regarding the first two questions, before the workshop, most students answered that sound is "what we listen" and "noise" (Q1_C), and usually, the picture they drew was something that produces sound, such as a radio, drum, or alarm clock (Q2_C). After the workshop, students answered that sound is a wave. They usually drew the same picture but added drawings of waves propagating from the devices that produced the sound that they represented before.

Figure 9 contains the answers to Yes/No type questions Q3_C to Q7_C, before and after the hands-on experiments developed during the workshop. After presenting the concepts of sound and carrying out the experiments, all fractions of Yes-answers increased except for question Q4_C (about bringing people well-being and a good mood). The core message of the negative effects associated with high levels of sound seems to have made students aware of this problem.

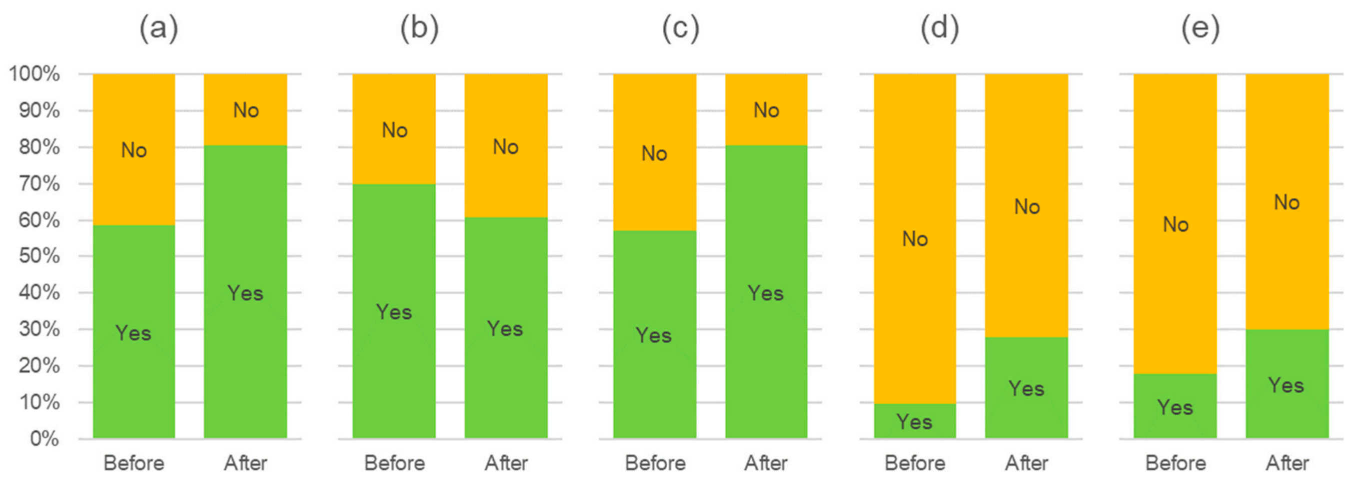


Figure 9. Answers of students to the questionnaires before and after the hands-on experiments: (**a**) Q3_C; (**b**) Q4_C; (**c**) Q5_C; (**d**) Q6_C; (**e**) Q7_C.

The student's perception of the negative effects of noise increased after the workshop (Figure 10). The average ranking of answers to question Q8_C increased from 4.0 ± 0.3 and 4.2 ± 0.2, although without statistical significance (p = 0.45). In a similar way, the perceived relationship between sound levels and health did not significantly increase after the workshops (Figure 11, the difference between the average rankings is not statistically significant, from 2.7 ± 0.3 to 2.8 ± 0.3, p = 0.68).

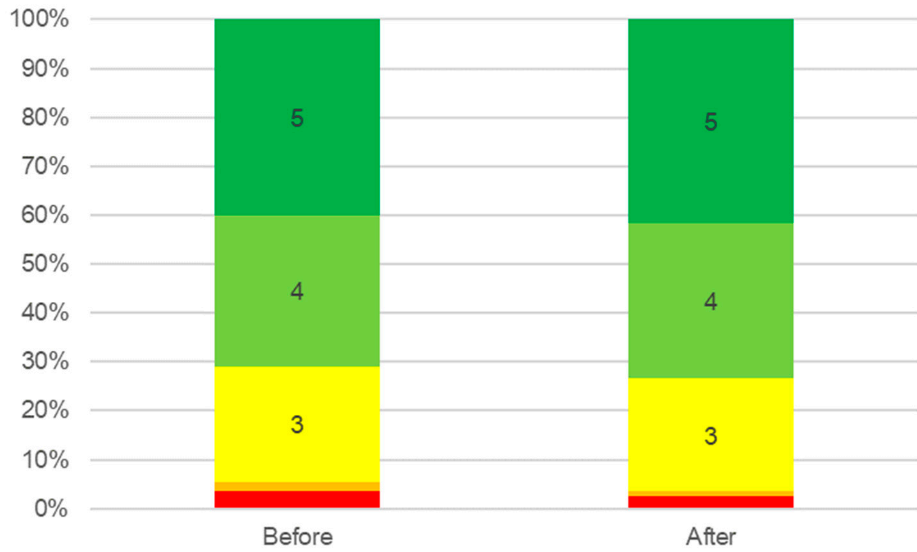


Figure 10. Answers of students to question Q8_C on the students' perception of noise risks for people. The numbers on the bars represent a five-point Likert's scale.

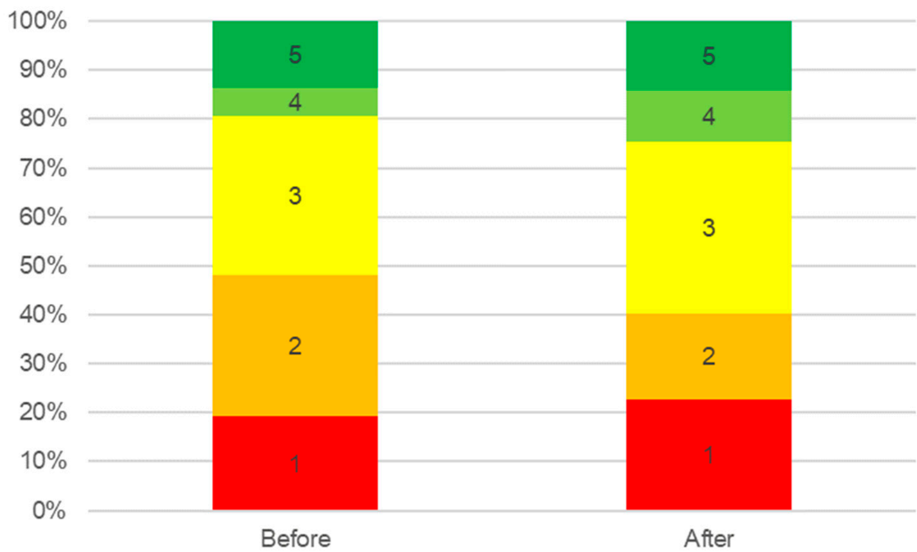


Figure 11. Answers of students to question Q10_C on the student's perception about how the theme of sound is related to people's health. The numbers on the bars represent a five-point Likert's scale.

Q10_C is a multiple-choice question in which 12 fixed options are presented (Figure 12). The choices "Airplanes" (Noise caused by airplanes taking off and landing near airports) and "Industrial noise" (Industrial noise: equipment in factories, machines, saws, etc.) show the highest prevalence both before and after the workshops. However, in the questionnaires passed before the workshops and in the questionnaires given after, the students included in their choices some activities that did not directly generate noise. This option shows that students were already aware of the negative effects of anthropogenic activities on the environment, functioning as a shield for the short-term perception of the effects of noise.

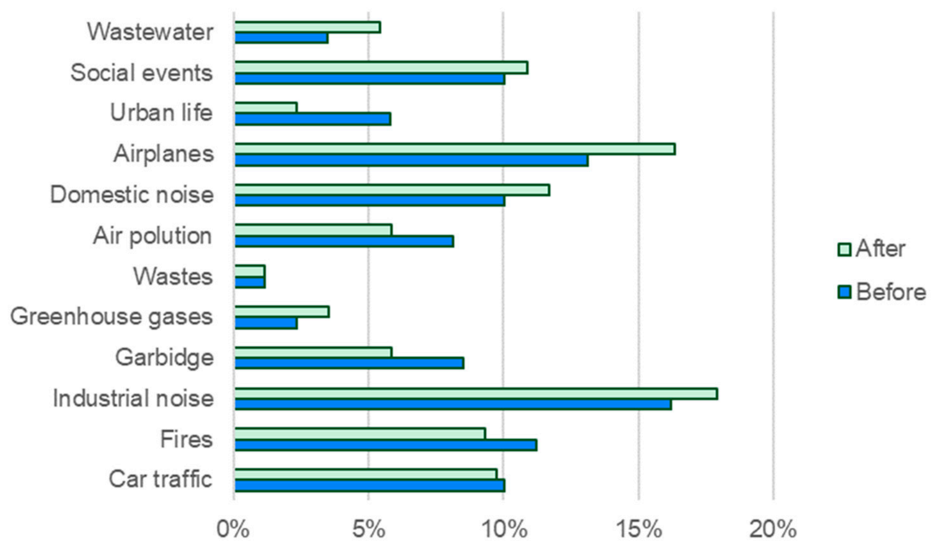


Figure 12. Answers of students to question Q11_C on the main causes/sources of noise pollution that affect living beings before and after the hands-on experiments.

The question Q11_C is also a multiple-choice type. The most negative effects of sound selected by the students were "Hearing loss" and "Headache" (Figure 13). Although some options not directly related to sound were selected by the students, as in the previous question, it can be observed that the frequency of those options tends to decrease after the workshops. In the opposite direction, the frequency of options related to the effects of noise tends to increase after the workshops.

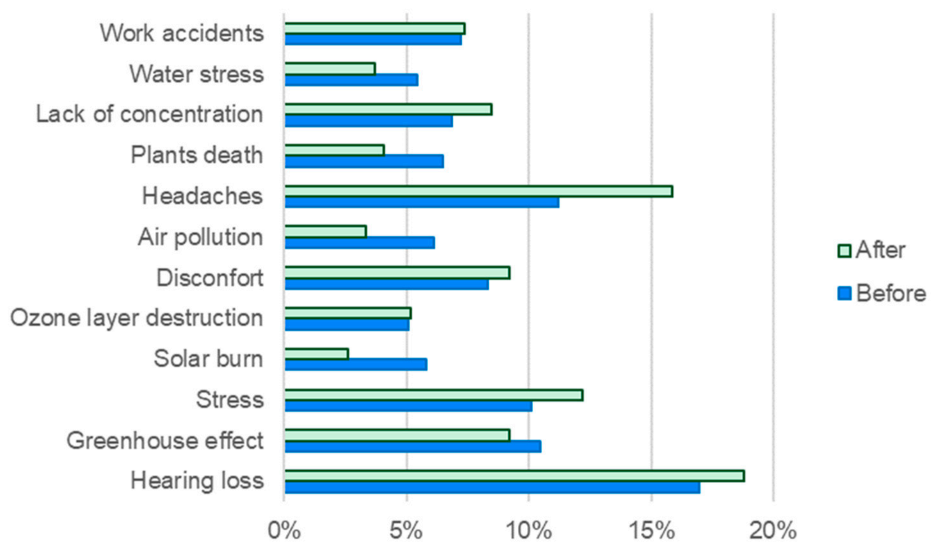


Figure 13. Answers of students to question Q11_C on the main topics that may be related to the consequences of sound exposure.

Based on students' answers to the questionnaires, it was verified that their perceptions about sound changed after the workshop (Questions Q1_C, Q2_C, and Q3_C). Moreover, although without statistical significance in some cases, they understood better the problems related to noise and its consequences. Also, some misconceptions regarding sound and other issues not related to sound were decreased (Table 8 and Figures 12 and 13). The next section provides a discussion of the results presented in this section.

6. Discussion of the Results from Data Analysis

According to the results from the answers to the questionnaires (Tables 5 and 6), it is verified that teachers improved their knowledge about the topics approached in the workshops. In fact, before the workshops, only seven of the seventeen goals were mentioned (Table 7), and one of the main objectives addressed in the workshops, "Good health and well-being", was not referred to by the teachers (Q2_A). In addition, from five possible options that seem most correct in what concerns SDGs (Q4_A), 50% of the teachers selected the option "Ability to create projects that will last in the future", a topic not necessarily related to SDGs. Moreover, regarding confidence and knowledge about introducing the topic of SDGs to students, no teacher felt "Very high" confidence to introduce SDGs to students before the workshop (Q5_A), and about 58% answered they had "Enough" confidence (Q5_A in Figure 5). However, after the workshops, the results improved, with 40% of the teachers answering "High" and 12% "Very high" (Q1_B in Figure 5).

Teachers' knowledge and confidence are crucial for teachers to gain motivation and develop the approach of the workshops in class [26]. Therefore, it is critical to promote their professional development. In this regard, teachers' answers to questions Q6_A and Q2_B (before and after the workshops) acknowledged the need to have training related to SDGs and sound (Figure 6). These results are related to the specialised knowledge provided in the workshop and, above all, the recognition of the importance of this theme. These findings are supported by the answers to the question about the "main difficulties to develop SD practices" (Q4_B), where the most selected option (61.5%) was "Lack of information and knowledge" (Table 6). Thus, the need for professional development and to support teachers in developing this approach in their schools is again reinforced. Moreover, 80.7% of the teachers answered that they intend to promote practical hands-on activities related to the theme of the workshop in their schools, followed by some examples (Q7_B and Q8_B, Table 6). This outcome confirms the motivation of teachers to develop this approach in class.

In addition, based on the results of the answers to questions Q7_A, Q8_A, and Q3_B (Figure 7), all teachers agree that schools should promote SD attitudes and practices and also recognise the importance of their role and the role of schools in promoting and disseminating SDG practices in the surrounding community.

Regarding the questions more related to the physics of sound, teachers also improved their knowledge about this topic, namely, the importance of measuring sound to understand if it is within safety standards or is at a dangerous level that can cause harmful effects on well-being and health. In fact, in question Q5_B about "applications of the sound phenomenon", 69.2% of the teachers selected the option "To prevent possible dangers" (Table 6). However, before the workshops, 88.5% of teachers considered noise dangerous to people's health (Q11_A, Figure 8). Moreover, after the workshop, the number of teachers considering it very dangerous to people's health increased to 96.2% (Q6_B, Figure 8). Therefore, teachers understood the need to measure sound to identify if there are dangerous levels to health, as well as to develop awareness in this matter. In fact, one of the open answers has to do with students: "To make students aware of the importance of moderating sounds in everyday life". This observation has to do with the recognition of their role in raising awareness of the dangers of noise pollution, in particular through the students.

Mentioning students, they also answered questionnaires before and after the workshops implemented in class (Table 8). After the workshops, it was noticed that students improved their knowledge about sound (Questions Q1_C, Q2_C, Q3_C). Moreover, except for question Q4_C about bringing people to well-being and a good mood, the "yes" answers to all questions from Q3_C to Q7_C increased (Figure 9) after the workshops, where concepts about sound and hands-on experiments were carried out (Section 4). Furthermore, students understanding of the negative effects of high levels of sound also increased (Q8_C, Figure 10), namely, "Hearing loss" and "Headache" (Q11_C, Figure 13), among others.

Therefore, the students understood the need to take into account the noise level and the dangers of noise pollution.

Finally, based on the results, it is concluded that collaborative projects among higher education and schools can have a critical role in the dissemination of SDGs, in particular in the context of the physics of sound.

7. Conclusions and Future Work

This study aims to raise awareness for SDGs (Sustainable Development Goals) in the context of the physics of sound, namely, by warning about the dangers of noise pollution and its consequences for health and well-being. In fact, environmental noise can have serious health consequences for populations subjected to this type of exposure repeatedly [4–8]. It is, therefore, essential to alert the population to the dangers associated with this type of exposure, how to diagnose dangerous situations, and, above all, what measures should be taken to prevent them. In this regard, higher education institutions can have a relevant role by intervening in the community since they are holders of specialised knowledge that should be placed at the service of society [17,18]. With a better-informed society regarding these issues and the need for noise prevention, better health conditions and higher productivity are provided, resulting in social and economic benefits for countries contributing to the SDGs. This paper presents an intervention project that includes an interdisciplinary approach in the context of STEM education [19,21,27] that involves workshops related to SDGs and the physics of sound targeted to elementary and secondary school teachers and students. Indeed, STEM hands-on experiments were performed in the workshops with teachers and students to make them understand the phenomena and their properties, as well as to make them aware of the dangers of noise pollution (Figures 1–4). In fact, sound is a science and real-world phenomenon, and mathematics was used, for example, in the measurement of intensity and frequency of sound, resorting to technology, which was also used to show the properties of sound, among other tasks.

The intervention project was developed in partnership with schools and a teachers' professional development centre to raise awareness for SDGs. In particular, the physics of sound was used to warn about the dangers of noise pollution and its consequences for health and well-being in industrial, educational, or environmental areas [4,7,8]. To prevent damage to health, it is necessary to monitor sound levels in the environment to check if these are within the safety standards and take measures whenever necessary to reduce them [11–13,16].

Based on this research, it was verified that teachers improved their motivation and knowledge in order to be able to develop hands-on practices related to SDGs in the physics of sound theme. In addition, they recognised the importance of implementing this approach in class to raise awareness of students for the issues related to noise pollution and involve the community in this objective. In fact, based on the questionnaires applied to teachers before and after the workshops, it was verified that teachers improved their confidence and knowledge to introduce the topic. However, they also found it very important to keep having training related to this approach. Therefore, they recognise the importance of their role and the role of schools in promoting and disseminating SDG practices. Moreover, based on student answers to the questionnaires, it was verified that their perceptions about sound changed after the workshop, and they improved their knowledge about problems related to noise and its consequences.

It is concluded that teachers and students increased their understanding of the contents and issues addressed in the workshops, namely, the dangers of noise pollution and measures to be taken to prevent them. Finally, it is concluded that collaborative projects can have an impact on teachers' knowledge and self-confidence to raise students' awareness of the SDGs and the issues related to noise pollution. Therefore, higher education institutions can have a crucial role by developing collaborative projects and supporting school teachers to disseminate and increase Sustainable Development practices in the community.

Because no similar studies were found in the literature connected to the relation about physics of sound and SDGs and about the need to raise awareness of the community about this theme, the results of this research can bring important contributions to literature, namely, how to disseminate and raise awareness of the SDGs in this context.

In the future, complementary actions (e.g., more workshops) will be developed to provide better insights into the awareness of noise and its relationship with the SDGs. Also, it is intended to involve more partners in order to reach the widest possible audience and, thus, help raise awareness of the issues addressed in the article, as well as to implement prevention measures. In addition, it is desirable to extend this study behind the local and national community to an international level, for example, in the context of an Erasmus+ project with European partners. Finally, regarding the implications for those interested in developing this type of project, we recommend promoting partnerships between experts from higher education organisations, municipalities, teacher training centres, and schools, among others. For example, higher education institutions can collaborate with municipalities to help develop projects and policies to effectively monitor sound levels in the community and what strategies should be implemented to ensure that safety standards are not exceeded.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the Instituto Politécnico de Tomar on 21 September 2020.

Informed Consent Statement: All data presented in this paper was authorised by the teachers, and this study was authorised by the Instituto Politécnico de Tomar directive board. Informed consent was obtained from all subjects involved in the study. In addition, the anonymity of all participants was guaranteed.

Data Availability Statement: Some data not presented in this study can be available on request from the corresponding author. However, part of the data is not publicly available to guarantee the anonymity of all participants.

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