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**NoiseCapture smartphone application as pedagogical support for education and public awareness**

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1 Teaching science subjects such as acoustics to the youth or general public audiences  
2 can be facilitated by illustrating physical phenomena or scientific issues through fun  
3 experiences. A few years ago, our team developed a smartphone application named  
4 NoiseCapture with the aim of offering to anyone the opportunity to measure their  
5 sound environment and to share their geolocated measurements with the community  
6 in order to build a collective noise map. Since, the NoiseCapture team members  
7 experimented numerous interventions in schools or scientific events for the general  
8 public based on the app for explaining not only societal and environmental issues  
9 related to noise but also for teaching acoustic notions and for addressing technical  
10 and scientific topics associated with sound measurement. The paper describes some  
11 of them implemented in particular in school context through training courses given  
12 to middle school and university students, as well as teachers of secondary school, that  
13 focused on basic knowledge in buildings and environmental acoustics, on the practice  
14 of acoustic measurement and on noise mapping. Some examples of interventions  
15 with the general public are also presented that were mostly integrated into scientific  
16 events.

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## 17 I. INTRODUCTION

18 The hardware and software developments of smartphones over the last decade and their  
19 wide distribution in the population have motivated several participatory projects related to  
20 the acoustic measurement by smartphones with the objective of proposing an alternative  
21 approach to simulation-based noise mapping (D’Hondt *et al.*, 2013; Maisonneuve *et al.*;  
22 Picaut *et al.*, 2019; Zuo *et al.*, 2016) or more precisely offering additional information on the  
23 perception of soundscapes (Li *et al.*, 2018; Radicchi *et al.*, 2018). The Directive 2002/49/EC  
24 thus afford the possibility of producing noise maps from measurements, which was not  
25 possible until now due to the large number of measurement points required. Despite the  
26 lower quality of the acoustic measurements compared to those of dedicated professional  
27 equipment, these research works have shown the relevance of such an approach (Aumond  
28 *et al.*, 2017; Ventura *et al.*, 2017) which also allows users to have feedback on their own sound  
29 environment and contribute to a civic and scientific approach. The NoiseCapture project  
30 was thus initially implemented in the context of the environmental noise assessment within  
31 the meaning of Directive 2002/49/EC with the aim of building a collaborative noise map  
32 from measurements by any user of geolocalized noise indicators by offering them in return  
33 information about their own sound environment (Picaut *et al.*, 2019). The NoiseCapture  
34 application was diverted from this latter as a support of education to secondary-school  
35 pupils, high school and university students, and teachers, but also for the wider public of  
36 citizens. The NoiseCapture application is part of a more global project, called Noise-Planet  
37 ([Noise-Planet.org](http://Noise-Planet.org)), which proposes tools combining acoustics and geographic information

38 science approaches for environmental noise assessment. The Noise-Planet project is led by  
39 the Environmental Acoustics Research Unit (UMRAE<sup>1</sup>) and the Laboratory of Sciences and  
40 Techniques of Information, Communication and Knowledge (Lab-STICC<sup>2</sup>), associated with  
41 other partners from the academic world and professional acoustic community.

42 Such use of mobile devices equipped with sound measurement applications with the aim of  
43 introducing some basis on acoustics was already undertaken and published by some authors.  
44 [Kawahara \*et al.\* \(2019\)](#) experimented an innovative approach to broach sound perception  
45 with primary school pupils by inviting them to collect sounds thanks to a tablet computer  
46 and to discuss together their perception of these sounds through a quiz based on recogni-  
47 tion of the origin of the recorded sounds. [Satoh \*et al.\* \(2016\)](#) and [Sakagami \*et al.\* \(2013;](#)  
48 [2019a;](#) [2019b\)](#) used smart mobile devices to teach about environmental and architectural  
49 acoustics. In their work, the authors compared A-weighted sound levels measured by a  
50 few applications installed on different iOS devices and a Class 1 sound level meter, before  
51 investing university students in the creation of sound maps based on measurements carried  
52 out with the smartphone application. [Elejalde-García and Macho-Stadler \(2019\)](#) also exper-  
53 imented to employ a smartphone application to learn concepts concerning indoor acoustics  
54 to high school and undergraduate students. They highlight that acoustic education may be  
55 a valuable way to prevent from noisy individual behaviours and thus to improve the acoustic  
56 comfort in the classroom since the pupils themselves seem to be the main noise source in  
57 primary school classroom according to [Dockrell and Shield \(2004\)](#). The use of mobile devices  
58 applications for educational activities concerning indoor acoustics to pupils of primary and  
59 secondary schools is also discussed by [Sakagami \*et al.\* \(2019b\)](#). The authors conclude their

60 paper by mentioning that smartphones applications, “Hush City or Noise Capture, will be  
61 in demand for educational purposes” in order to integrate perceptual information. Indeed,  
62 the two latter applications provide a useful participatory sensing framework dedicated to  
63 two complementary objectives: the Hush City application is mainly devoted to identify and  
64 evaluate quiet areas in cities ([Radicchi, 2019](#)) while, as already explained above, the Noise-  
65 Capture application aims at building a participatory noise map. Both applications rest upon  
66 a methodology that combines a citizen sensing approach and a feedback to the community,  
67 which allows to involve the users in the assessment of their sound environment as well as to  
68 raise them awareness of the importance to preserve quiet areas and to make quieter cities  
69 ([Suarez and Arenas, 2018](#)).

70 The present paper precisely details the use of the NoiseCapture application with var-  
71 ious groups of participants from school children to teachers and the general public. The  
72 educational interventions were implemented in the form of specific events of collaborative  
73 production of noise maps (NoiseCapture Party) with the objective of raising awareness of  
74 the problematic of noise environments, or by using the NoiseCapture application as a pocket  
75 sound level meter for various problems of acoustic measurement. The first section describes  
76 the measurement and data extraction processes. Then, the second section presents the use  
77 of these data in different contexts in school, teacher training and general public contexts.  
78 Finally, the third section discusses the teaching opportunities related to the use of Noise-  
79 Capture to address technical and scientific issues.

## 80 II. NOISECAPTURE MEASUREMENTS AND COLLECTED DATA EXTRAC- 81 TION

### 82 A. NoiseCapture measurement and calibration

83 A measurement with the NoiseCapture application takes place in three steps. The first  
84 step consists in starting the simultaneous measurement of acoustic indicators (such as the  
85 one-second third octave band equivalent sound levels ( $L_{Aeq,1s}$ ) and GPS location, during  
86 which the real-time evolution of sound level is displayed in the form of a classical  
87 spectrum or spectrogram, or else as a map of measurements. The second step, that begins  
88 when the measurement is stopped, allows the user to provide optional information such as  
89 a short description of the sound environment, tags describing the measurement conditions,  
90 pleasantness and sound sources present, or eventually a party code if the measurement falls  
91 within the framework of a NoiseCapture Party event<sup>3</sup>. The third and last step allows to  
92 view and explore the measurements through different noise indicators (*e.g.* equivalent sound  
93 levels, spectrum, percentile values) or overlaid on the community map. A help menu in the  
94 application also gives various information on the use of the application as well as basic  
95 notions in acoustics to carry out and interpret the measurements.

96 Like most measurement devices, the NoiseCapture application must be calibrated, accord-  
97 ing to the selected smartphone, in order to produce expected results. In the NoiseCapture  
98 application, it is necessary to define a specific gain to correct the acoustic measurement  
99 that can be obtained by using a manual or automatic calibration protocol, and is stored  
100 in the Settings of the application. Two manual calibration procedure are available which

101 consist either in correcting the sound level obtained by the application by comparison with a  
102 simultaneous measurement with a professional sonometer, or in using an acoustic calibrator  
103 if an external microphone is connected to the smartphone. Alternatively, NoiseCapture also  
104 proposes two automatic calibration procedures based on a comparison either with an already  
105 calibrated smartphone used as a reference through a communication protocol between the  
106 reference smartphone and the smartphones to be calibrated<sup>4</sup> by using the internal generation  
107 of pink noise or on the basis of background noise, or with expected noise levels provided by  
108 a numerical model by performing vehicle passage noise measurements close to a few road  
109 sections with constant speed driving conditions ([Aumond \*et al.\*, 2020](#)).

## 110 **B. Data reading and extraction**

111 Data collected from NoiseCapture can be exploited in different ways. The most common  
112 need for users is to visualize measurements in the application. The data can be directly read  
113 in the NoiseCapture application during or at the end of the measurement or a posteriori  
114 in the measurement history. This latter alternative also allows to extract data from the  
115 NoiseCapture application by selecting the expected measurements in the list and exporting  
116 them in a `.zip` file that will contain three files: the metadata of the measurement (*i.e.* the  
117 date and time of the measurement, the device manufacturer, the mean equivalent sound  
118 level or the gain of calibration), a descriptive text with information about the exported data  
119 and the measurement track with information on the geolocation accuracy or else the third  
120 octave band sound pressure levels.



121 The NoiseCapture application allows the user to share its measurements by uploading  
122 them to the NoiseCapture remote server in order to be used for producing noise maps, but  
123 also to be shared again with the community. All the data uploaded by users to the database  
124 fully respects the privacy of users as no personal data is collected, a unique identifier being  
125 only created at the installation of the application and provided with user data which allows  
126 to associate different measurements to the same application installation. The data from the  
127 remote server can be used in four different ways. Firstly, raw data shared by contributors  
128 can be uploaded in the form of `.geojson` files, this approach being mainly address to the  
129 scientific community<sup>5</sup>. Secondly, pre-processed daily data are also available from the web  
130 page <https://data.noise-planet.org/noisecapture/> as `.geojson` files distributed un-  
131 der open license (ODbL, see for more details) and organized as `.zip` files by country (Bocher  
132 *et al.*, 2017). Each archive contains three files by administrative region that correspond to  
133 data collected along a track (file `.tracks.geojson`), post-processed data aggregated in  
134 hexagons of 15 m radius (file `.areas.geojson`) and one-second measurement points data  
135 (file `.points.geojson`). Thirdly, a 3-years extraction of the NoiseCapture database is also  
136 freely available for download and use, according to the OdbL license, as a relational Post-  
137 GIS database (Picaut *et al.*, 2021a,b). Finally, the data processed by means of the OnoMap  
138 Spatial Data Infrastructure (SDI), that is also based on free and open source tools compliant  
139 with OGC standards (Bocher *et al.*, 2016), are also available in the form of Web Map Service  
140 (WMS) layers with the  $L_{A50}$  and  $L_{Aeq}$  levels inside the hexagonal cells (`noisecapture_area`  
141 and `noisecapture_area_laeq` respectively), as well as all the measurement point locations

142 provided by the entire community (`noisecapture_leaflet_point`) or within the framework  
143 of a NoiseCapture Party (`noisecapture_points_party`).

### 144 **III. USE OF NOISECAPTURE FOR PEDAGOGICAL EVENTS**

145 The ease-of-use of the NoiseCapture application allows to address a diverse audience that  
146 includes both youths and adults. Its use as a pedagogical material was investigated through  
147 some interventions in different contexts from school environment to the general public as  
148 well as teacher training.

#### 149 **A. In school environment**

150 NoiseCapture can allow to improve the student investment in pedagogical activities by  
151 offering a playful way for both teaching basis on acoustics and doing prevention concerning  
152 the health and environmental risks associated with noise.

##### 153 **1. “Immersion Science“ event (secondary/high school)**

154 One of the first interventions in school environment based on NoiseCapture took place  
155 within the framework of the “Immersion Science“ (IMS) event. This annual operation jointly  
156 carried out since 2011 by the region of Brittany (France), the academy of Rennes in charge  
157 of education in the region and the French National Centre for Scientific Research (CNRS),  
158 aims at immersing high school students into the world of Science to foster their course guid-  
159 ance toward scientific disciplines. Renewed each year in the nautical centre of the Île-Tudy

160 peninsula (France), students attend during a week around twenty workshops and confer-  
161 ences that are held by researchers who showcase their scientific activities. The proposed  
162 interventions involving NoiseCapture were undertaken in 2018 and 2019, and consisted in a  
163 short presentation of acoustics basics and research activities related to environmental noise  
164 assessment followed by a NoiseCapture party with the students accompanied by their teach-  
165 ers. The measurement workshop lasted for about two hours and was established by dividing  
166 the covered area into 5 sub-zones, each of these latter being allocated to one or more student  
167 pairs equipped with Android smartphones with the pre-installed NoiseCapture application.  
168 Smartphones were first calibrated by using the automated process based on an already cali-  
169 brated smartphone as mentioned in Sec. II A (figure 1), then student pairs roamed their areas  
170 while performing measurements for around one hour. The 2018 and 2019 sessions gathered  
171 13 and 23 contributors respectively, who shared 45 itinerant measurements the first year  
172 and 192 the second year for respective total durations of 4h38mn and 4h48mn. The maps  
173 generated from those two sessions are given at Figure 1. One can note the windy conditions  
174 that significantly impacted the first session measurements (*i.e.* higher sound levels). An  
175 online map that aggregates the two-year sessions and participant tracks is available here:  
176 [http://noise-planet.org/map\\_noisecapture/index.html#17/47.84239/-4.16735/](http://noise-planet.org/map_noisecapture/index.html#17/47.84239/-4.16735/).

## 177 2. “*Research Passport in Pays de la Loire*” event (secondary/high school)

178 A second intervention was carried out in 2018 and 2019 as part of the operation named  
179 “Research Passport in Pays de la Loire” led by the Regional Educational Pact of the Pays de  
180 la Loire Region (France) and supported by the educational academy of Nantes. This opera-

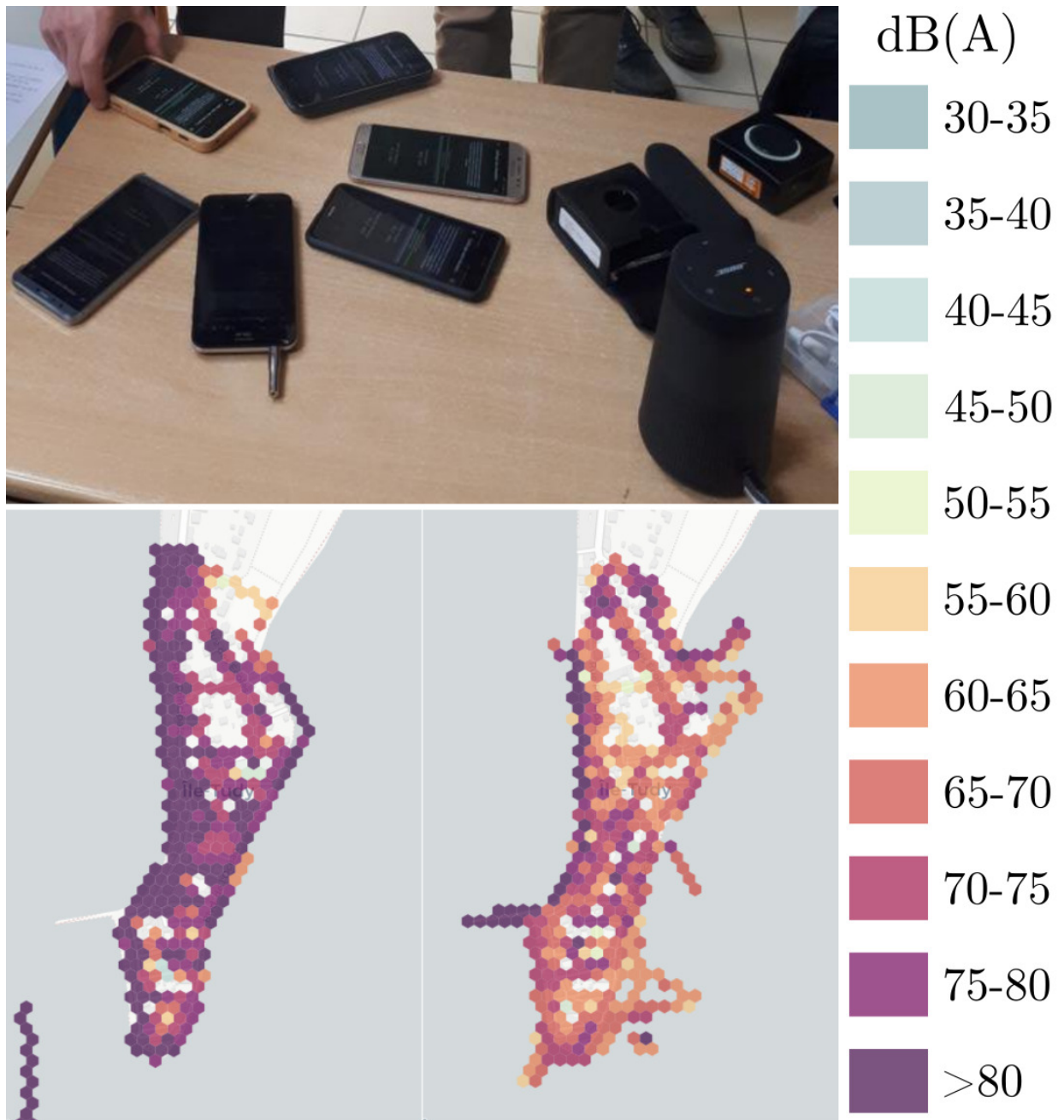


FIG. 1. (color online) NoiseCapture parties organized within the framework of the Immersion Science events: (top) calibration of the smartphones, sound maps produced in (bottom left) 2018 and (bottom right) 2019.

181 tion was addressed to young high school students and aimed at allowing them to discover the  
182 research community and laboratories in the region through meetings with researchers or a  
183 visit of a laboratory. Students enhanced their analytical skills related to scientific and techni-  
184 cal topics and have the opportunity to convey their learning by elaborating a communication  
185 support on a specific issue proposed by the researchers. The project ongoing throughout the  
186 school year allowed numerous exchanges with scientists with a visit of their laboratory and  
187 school’s interventions of researchers. A day of restitution was finally organized at the end of  
188 the school year during which classes orally presented their project in a lecture hall, as well  
189 as in the form of workshops and demonstrations. This project undertaken by the college  
190 students of the high school of the City of Bouaye (France) in partnership with researchers  
191 of the UMRAE over the period from October 2018 until May 2019 (2 hours per week) dealt  
192 with the issue of “calibrating sonometric applications for smartphones for the *in situ* mea-  
193 surement of sound environments” what is of major concern as it raises numerous scientific  
194 and technical issues concerning, for example, the methodology or metrology (Celestina *et al.*,  
195 2018; Garg *et al.*, 2019; Guillaume *et al.*, 2016). In addition, the concepts discussed in class-  
196 room and in workshops with the college students fit in well with the curriculum taught in  
197 1<sup>st</sup> year of “Laboratory Science and Technology”. Each stage of the project led to inter-  
198 esting and fruitful discussions from the implementation of the experimental protocol and  
199 the formation of student groups for *in situ* measurements through a NoiseCapture Party to  
200 the processing and analysis of the collected data (figure 2). A technical report was finally  
201 written by students that explains both the Research Passport operation and the scientific  
202 results of the project<sup>6</sup>. Besides, during the project, the students had the opportunity to visit



FIG. 2. (color online) Experimental campaign carried out within the framework of the Research Passport operation: (left) location of measurement points, (top right) resulting map and (bottom right) comparison of smartphone measurements with sonometer results.

203 the UMRAE outstanding facilities such as the semi-anechoic room. It is interesting to note  
 204 that it was through this intervention that the idea of developing an alternative calibration  
 205 method came about, which then led to a specific research work and the publication of the  
 206 article by [Aumond \*et al.\* \(2020\)](#), who are UMRAE researchers involved with the students.

### 207 3. ‘A week outside the classroom’ event (University student)

208 A third intervention was undertaken under the program “A week outside the classroom”  
 209 proposed to first-year students in their curriculum at the Faculty of Geography of the Uni-  
 210 versity of Nantes. The operation aims at allowing students to develop their knowledge and  
 211 skill on a field and an object of study, to gain more independence and to comprehend ge-

212 ographer work. The 2019 and 2020 sessions focused on the investigation of the soundscapes  
213 of the city of Nantes (France) and gathered around 120 students each year divided into  
214 groups of five who could attend half-day workshops allowing them to get more familiar with  
215 acoustic notions from both physical and perceptive points of view, to grasp the concepts  
216 behind the approaches of the participatory measurement and perceptual data collection, and  
217 to orally report as a team their work at the conclusion of the week. In this way, physical and  
218 subjective data were collected by groups of students for 20 listening points per group, which  
219 approximately represents 650 listening points for the two years (figure 3). The listening  
220 points were chosen as being representative of various sound environments over the pedes-  
221 trian and road network and consisted in practice in 3-minute measurements of the  $L_{Aeq}$  and  
222  $L_{A90}$  indicators at the same time as one to five students completed a perceptual question-  
223 naire on the sound environment. Both physical and subjective collected data were finally  
224 compared and discussed by the students in addition to a geospatial analysis of the sound  
225 data aggregated during the NoiseCapture Party which was presented in the closing day of  
226 the week, what enabled to highlight the collective benefit of the collaborative approach.

#### 227 *4. Noise health and learning awareness school project (middle school)*

228 These last three interventions fit well within the scope of application planned for Noise-  
229 Capture, namely proposing a participatory and freely accessible tool dedicated to any user  
230 for outdoor acoustic measurements. Indeed, the GPS position is required to be able to re-  
231 late sound measurements with geographical locations, what can not be reached yet indoor.  
232 The following operation overcame this issue by implementing an adapted protocol to allow



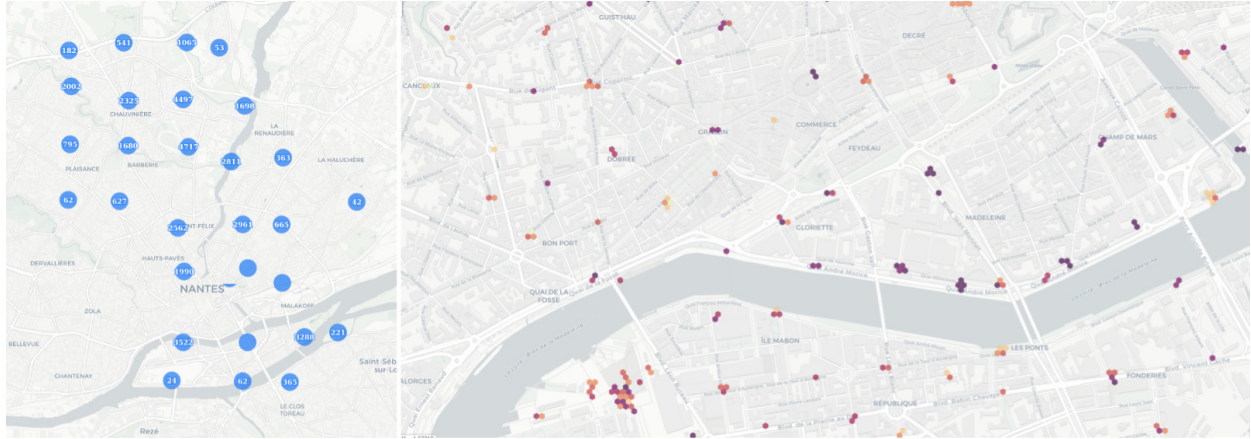


FIG. 3. (color online) Listening points investigated within the framework of the program “A week outside the classroom”: (left) amount of data at listening points; (right) sample of the measurement results.

233 the creation of noise maps indoor. This latter was undertaken in 2018 at the Gutenberg  
 234 technical middle school (Illkirch-Graffenstaden, France) as part of a project of awareness  
 235 concerning noise-related risks on health and learning. The training courses of the establish-  
 236 ment on digital systems, multimedia visual communication, graphic and printed productions  
 237 were involved in the project, which was structured around four components: the collection  
 238 of general information concerning noise, the study of the noise sources in the school, the  
 239 information on health and learning effects of noise, and the implementation of an awareness  
 240 campaign and actions in the school. The project started with the creation and analysis of  
 241 an online questionnaire directed at the students and teachers what enables to gather their  
 242 perception of noise in school and more specifically to locate the major “noise black-spots”  
 243 among which the printing facilities workplace was highlighted. The intervention proposed by  
 244 the UMRAE team took place in two stages: a short lecture on some generalities in acoustics



245 from basic physical phenomena and indicators to the noise measurement and its effects on  
246 health and learning, and a collaborative experimental campaign aiming at establishing a  
247 noise map of the workshop of printing facilities from a series of measurements performed  
248 by the students with their personal smartphones. Before this operation, students prepared  
249 markings on the floor, which was facilitated by the presence of floor tiles, in such a way  
250 as to create a grid of one-meter apart measurement points, each assigned of an index that  
251 consists of a letter representing one Cartesian direction and a number for the other direction  
252 on a horizontal plane (figure 4). The collective measurement campaign was preceded by the  
253 calibration of all smartphones by using the manual process of the NoiseCapture application  
254 with a professional sonometer (see section II A). Then, the measurement campaign was car-  
255 ried out and organized by grouping schoolchildren by pair with one smartphone and a sheet  
256 of paper on which they reported the collected data at each point. Each pair of schoolchildren  
257 divided up alternately the roles: one performed the measurement above a marking, while  
258 the other wrote up the equivalent sound pressure level  $L_{Aeq,10s}$  into a table with the related  
259 marking index. The pairs of schoolchildren went all over the workspace until its full coverage  
260 by the entire class. This operation was carried out twice under two distinct conditions of  
261 printing machine load: an extreme situation for which all machines were operating and an  
262 ordinary working case for which only few printing facilities were running (figure 4).

263 In addition to these actions, schoolchildren also created awareness-raising materials in the  
264 form of videos, leaflets and posters. The general school project entitled “Noise and us” (“*Le*  
265 *bruit et nous*” in french) was submitted to compete in the “CGénial” competition organised  
266 every year by the Foundation “CGénial” and the french Ministry of National Education

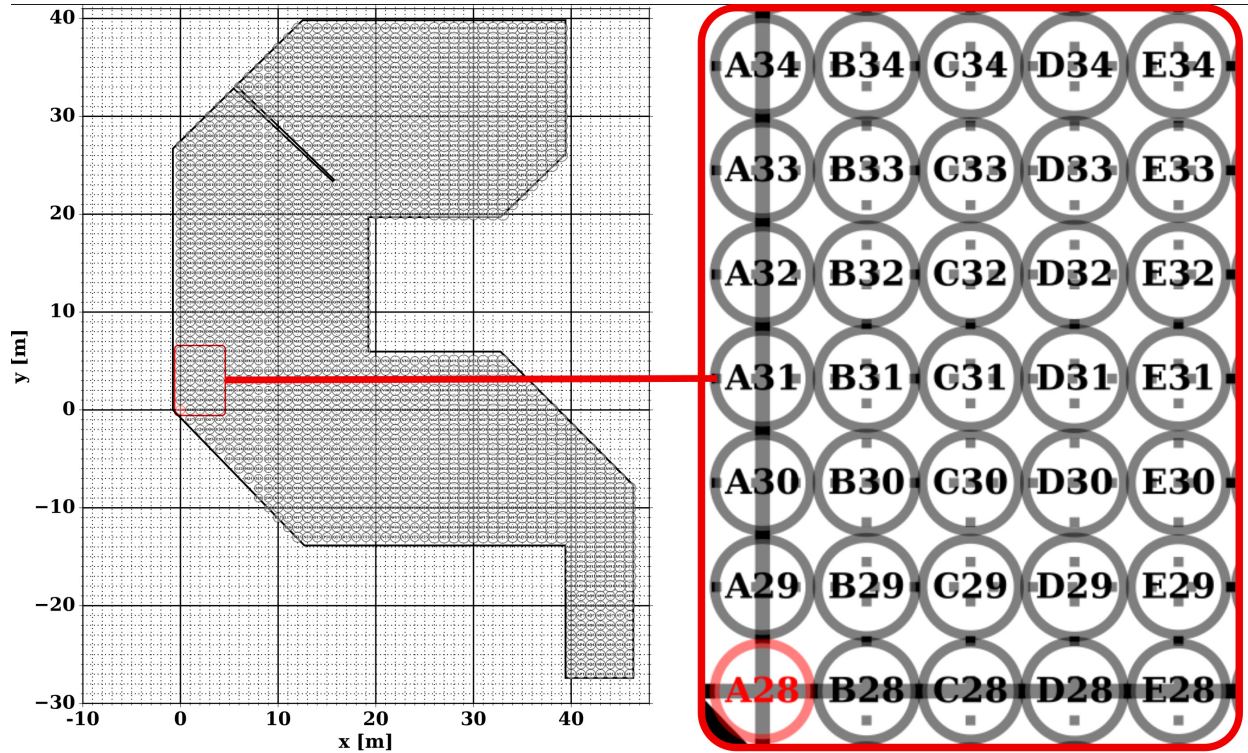


FIG. 4. (color online) Grid of measurement points implemented (left) over the printing facilities workshop (right) with related indexing (the origin index appears in red online).

267 through the program “Sciences at School”. This scientific contest aims at promoting sci-  
 268 ences and is addressed to secondary-school and College students who have to carry out an  
 269 innovative project through a multidisciplinary team approach combining different scientific  
 270 subjects such as life and earth sciences, technology, physics, chemistry or mathematics. The  
 271 project was selected for the final of the “CGénial” competition<sup>7</sup> based on a written report  
 272 of tasks undertaken as part of the project. The event took place at the “Cité de l’Espace”  
 273 in Toulouse on 25 May 2018 during which a trio of schoolchildren accompanied by their  
 274 teacher received the “CGénial” diploma.

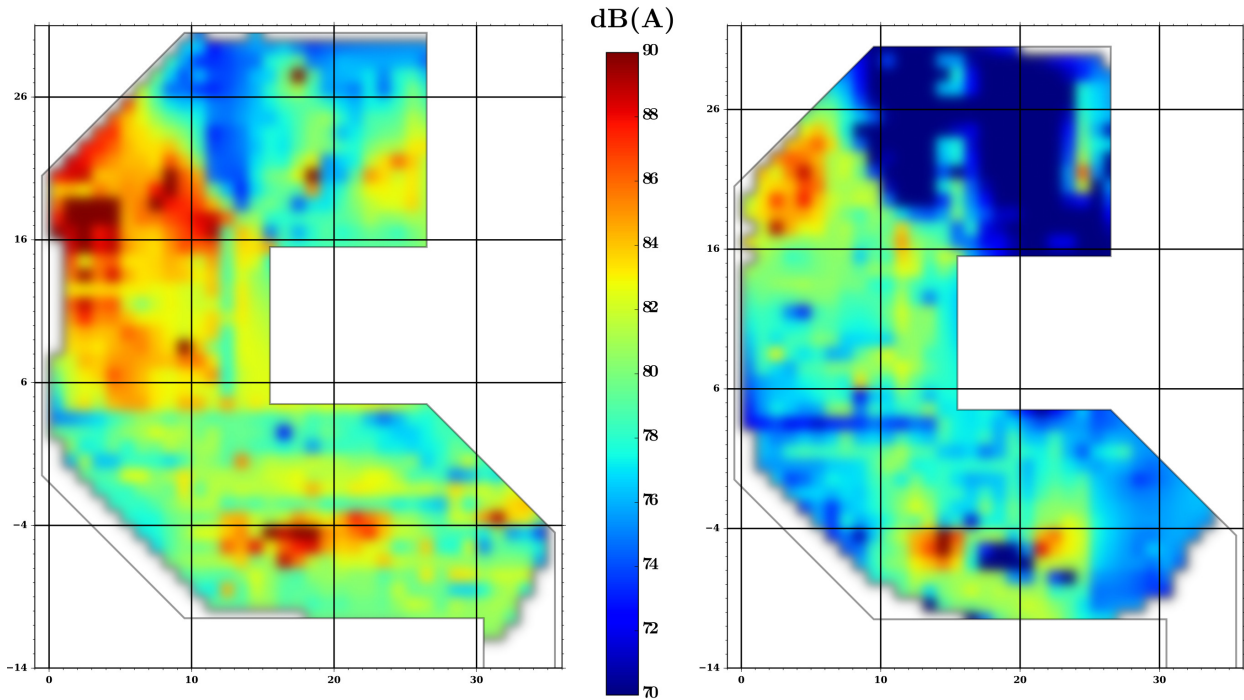


FIG. 5. Noise maps of the printing facilities workspace for (left) the extreme case for which all printing machines in operation and (right) in current use.

275 **5. Pedagogical toolkit for teachers**

276 Following the last successful event, a pedagogical toolkit (available here [https://](https://www.umrae.fr/en/productions/software-apps-and-computing-methods/)  
 277 [www.umrae.fr/en/productions/software-apps-and-computing-methods/](https://www.umrae.fr/en/productions/software-apps-and-computing-methods/) and named  
 278 “*CARTO\_ACOUSTIQUE\_INTERIEURE*”) was implemented to allow any teacher to man-  
 279 age similar actions with students. It consists of a slideshow concerning basics in acoustic  
 280 focusing both on the health and societal impacts of noise and the good practices for acoustic  
 281 measurement, and of a software with a graphical user interface. The software allows to  
 282 build the grid of indexed points based on a spreadsheet file that contains the coordinates of  
 283 the room corners with a user-adjustable resolution and to build the noise map in the form



FIG. 6. (color online) Graphical user interface (in french) of the pedagogical toolkit to build a noise map from indoor measurements over a grid of points.

284 of coloured measurement dots, interpolated data and isosurfaces as interactive `.html` files  
 285 (figure 6).

286 This educational kit was tested in a similar project undertaken in collaboration with  
 287 a classroom of cabinet-making students of the Duguesclin Arts High School (*“Lycée des*  
 288 *métiers d’art Duguesclin”*), on the initiative of their physics-chemistry teacher. The short  
 289 lecture was provided by a non-acoustician member of the Noise-Planet team. The mea-

290 surement campaign focused on a woodworking workshop (figure 7, left) that includes fifteen  
291 wood-working machines and a ventilation system. As previously, students were organised in  
292 pairs who achieved equivalent sound levels measurements of 5-second duration owing to the  
293 stationarity of the noise sources and the practical session consisted in three stages:

- 294 • first, students materialized the 437 measurement points using stretched ropes with  
295 falling ropes tied every 1 m (figure 7, right), what took about 4 hours;
- 296 • then, the student’s smartphones were calibrated thanks to the automated process  
297 based on an already calibrated smartphone;
- 298 • finally, three series of measurement were carried out in around one hour and a half with  
299 alternatively only the ventilation system in operation (figure 8, top), wood-working  
300 machines switched on (figure 8, center) and machines chopping wood (figure 8, bot-  
301 tom).

302 Student pairs rewrote their measurements into spreadsheet files that allow to build the three  
303 noise maps presented at figure 8.

## 304 **B. Teacher training context**

305 The “Houses for science” (*“Maison pour la science” in french*<sup>8</sup> is a project launched in  
306 2012 at the initiative of the Academy of Sciences with the financial support of the program  
307 “Investments for the future” (*Investissements d’Avenir* in french) that aims at proposing  
308 professional development courses to teachers from the primary to secondary levels. The  
309 “Houses for science” network includes eleven “Houses for Science” under the coordination of





FIG. 7. (color online) Pictures (left) of the woodworking workspace and (right) of the marking method.

310 the Foundation “La main à la pâte” (what can be translated into “Get involved”). Teachers  
311 can thus subscribe to training programs addressing different scientific and technical topics  
312 in order to help advancing their education practices through an interdisciplinary approach  
313 of inquiry-based learning.

314 The UMRAE team proposed a training module that was part of a program entitled “On  
315 my signal, sound at will!” (*“À mon signal, son à volonté !” in french*) in which physical  
316 aspects concerning indoor and outdoor acoustic phenomena were addressed both in the form  
317 of short lectures and practical implementations. The module was divided into two sessions  
318 that focused alternately on building and environmental acoustics (the last one is not detailed  
319 in this paper).

320 Concerning building acoustics, the notions of stationary phenomena and modal sound  
321 fields in rooms as well as wall acoustic absorption and transmission were approached with

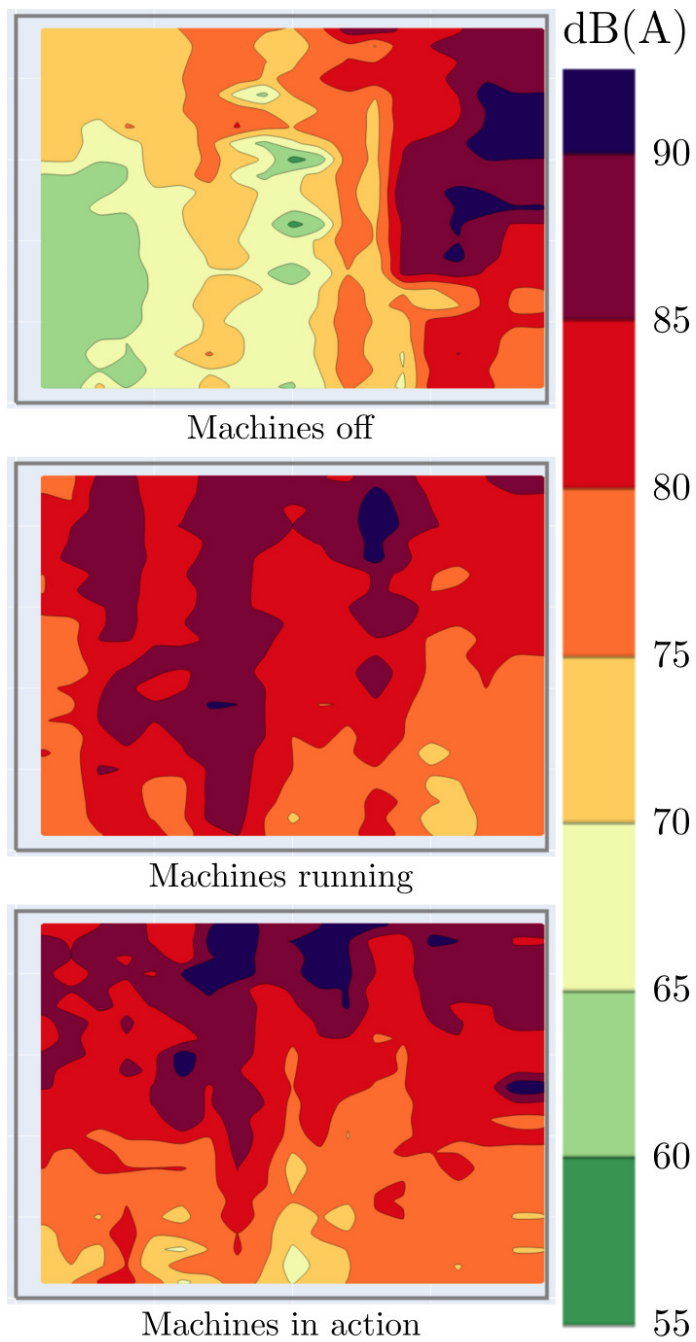


FIG. 8. (color online) Noise maps of the woodworking workspace for the three series of measurement: (top) with only the ventilation system in operation, (center) woodworking machines in no load operation and (bottom) chopping wood.

322 practical examples by using room scale models and therefore adapting the frequency range  
323 of the experiment.

324 The following well-known acoustic phenomena were then highlighted: stationary phenom-  
325 ena in rooms, acoustic absorption by walls and acoustic transmission through walls. The  
326 presence of eigenmodes in rooms was demonstrated by emitting a sine wave successively  
327 adjusted to some eigenfrequencies of the scale model with the help of a smartphone sound  
328 generator positioned in a room corner, and by simultaneously measuring the sound pressure  
329 level at different places of the room scale model with the NoiseCapture application as a  
330 sound level meter. The longitudinal and transverse modes of the room were observed as the  
331 sound level is reinforced and reduced in the regions of the nodes and antinodes respectively.

332 Then, acoustic absorption by walls was highlighted by, first, measuring the sound level in  
333 the scale model without absorbent material and, then, successively repeating the experiment  
334 with one, two, three or four absorbent layers on the surrounding walls. This experimentation  
335 enables to estimate the acoustic gain provided by the addition of absorbent systems. Finally,  
336 the acoustic transmission phenomena, and more particularly the mass-frequency law related  
337 to the acoustic insulation to airborne, was studied by inserting a wall into the scale model in  
338 such a way as to create two rooms. The first experiment consisted in repeating twice a mea-  
339 surement at a single frequency and in varying the density of the separating wall successively  
340 by introducing a balsa slab then a plasterboard, what enables to highlight the improvement  
341 in acoustic insulation when increasing the wall density. The second experiment, for a given  
342 wall, aimed at illustrating the increase of the acoustic insulation when the frequency of the  
343 signal increases. This experimentation was performed using a smartphone as a sound source



344 generator positioned in one of the rooms, while another smartphone alternately measured  
345 with NoiseCapture the sound level  $L_E$  in the emission room and  $L_R$  in the reception one,  
346 then estimating the acoustic transmission loss through the panel  $TL = L_E - L_R$ .

347 Lastly, the effect of a doubling up of the wall with a second panel was analyzed in com-  
348 parison to a single panel of equivalent density. This latter experiment allowed to illustrate  
349 the mass-spring-mass system principle and to demonstrate the gain in sound insulation with  
350 the double partition wall. For this experimentation, a similar protocol as the previous one  
351 with two smartphones (an emitter and a receiver) was implemented.

### 352 C. In a general public context

353 The NoiseCapture application stand for attractive and interactive tools that enable to  
354 organize participatory workshops and to bring people together around the environmental  
355 noise issue. An event was organized by the agglomeration of Bastia (Corsica, France -  
356 60,000 inhabitants) that illustrates the benefit of using these media to involve people in an  
357 urban development project. The city desired to implement a public awareness approach in  
358 collaboration with its city dwellers before the implementation of noise reduction actions.  
359 A NoiseCapture Party was set up within the framework of this project in October 2018  
360 with some members of the NoiseCapture team. This event was organized with high school  
361 students and the general public, in two stages: a first intervention in the afternoon that  
362 involved two classrooms of 9<sup>th</sup> grade students (*i.e.* approximately 40 students) accompanied  
363 by four teachers, and a meeting time, in the late afternoon, opened to the public. In  
364 both cases, a presentation was made by the NoiseCapture team members who addressed

365 the noise pollution issues and the general approach behind the NoiseCapture ecosystem.  
366 Then, the team helped participants to calibrate their smartphones and finally accompanied  
367 them in using the smartphone application and contributing to the party by carrying out  
368 measurements in good conditions. Besides, a two-week extension was set up to allow the  
369 participants to keep contributing to the noise map after the event. In total, 19 contributors  
370 uploaded 16 hours and 37 minutes of measurements (507 measures) with more than 50,000  
371 points over these two weeks, as illustrated at figure 9<sup>9</sup>. A restitution in the form of closing  
372 plenary brought together the participants, local elected representatives and journalists, that  
373 was subsequently used as a means of public communication and awareness raising to the  
374 inhabitants and was the subject of various press articles.

375 Following the same example, numerous other NoiseCapture Parties were implemented  
376 as for example within the framework of the “Festival of Science” in 2018 in Nantes<sup>10</sup> and  
377 Strasbourg<sup>11</sup>. Since 2017, half of the 26 NoiseCapture Parties co-organized by the members  
378 of the team in 4 countries (France, Spain, Italy, Ecuador) dealt with education. Some of these  
379 parties are repeated each year as the teachers who co-organized the event have incorporated  
380 it in their education program (*e.g.* Immersion Science, Universidade da Coruña, ...), with  
381 rich exchanges with the NoiseCapture team.

#### 382 **IV. DISCUSSION**

383 Android devices are nowadays very widespread in the general public, which makes it  
384 possible to have a large number of people, whether young or adult, equipped with an acoustic  
385 sensor and thus facilitate the setting up of experiments. Their use as training materials allows

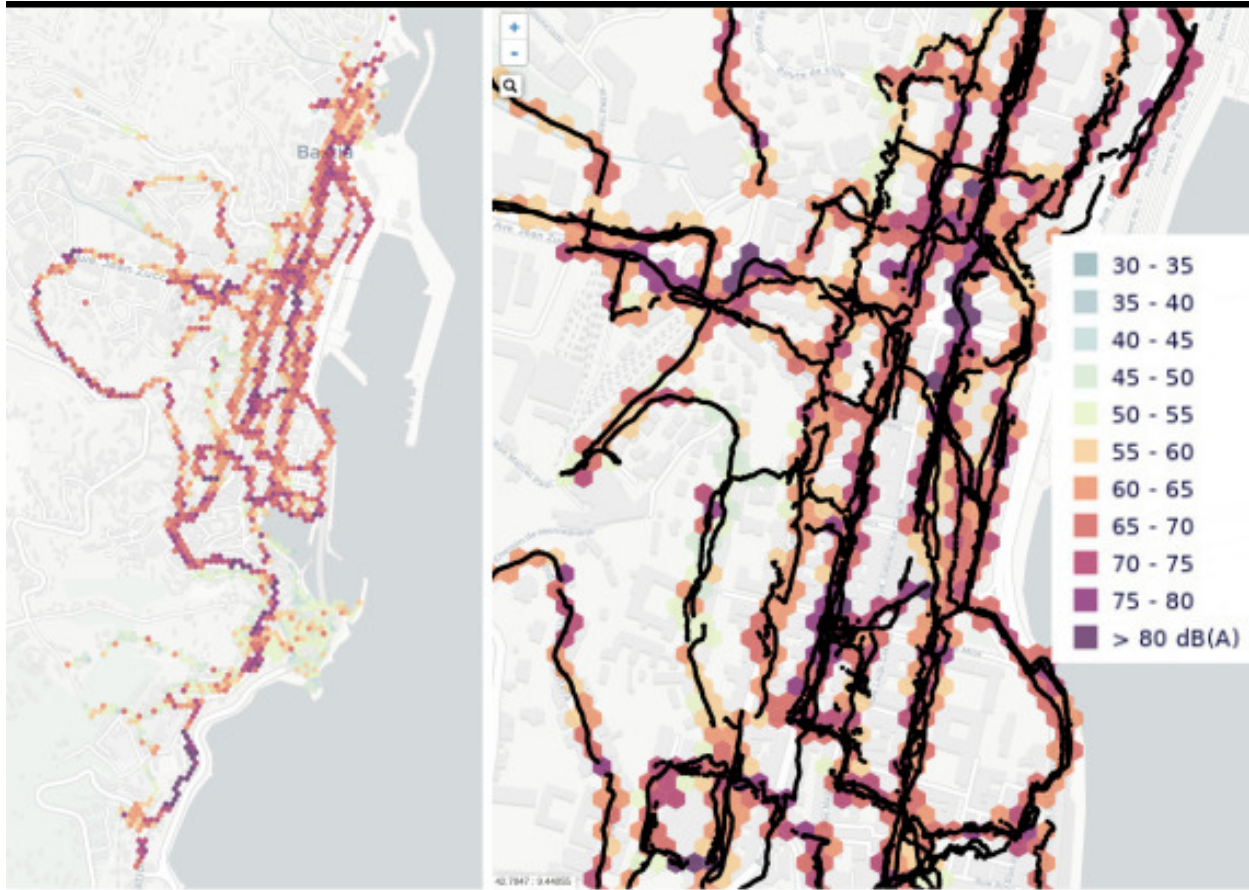


FIG. 9. (color online) Noise map produced (left) on the city of Bastia and (right) downtown zoom with measurement tracks.

386 different concepts to be addressed with high school pupils or students, and more generally  
 387 with the general public.

388 In an educational context as in most of the interventions presented above, its integration  
 389 into training activities offers a good opportunity to tackle technical issues concerning the  
 390 accuracy and reliability of such acoustic sensors in comparison with professional systems.  
 391 Questions relating to measurement uncertainties or even sound signal processing can thus be  
 392 addressed to awaken participants' critical sense concerning the results of their measurements,

393 and more generally on acoustic performance and noise pollution information that they may  
394 encounter in their daily life.

395 During all the events, an essential step may be the calibration of the smartphones, which  
396 allows participants to understand the difference between a smartphone and a reference de-  
397 vice, by observing the bias between the different devices. One of the messages to be passed  
398 on to the public is therefore to keep a critical mind on both the measurement and calibra-  
399 tion protocols. However, the lack of smartphone calibration, for example in the absence  
400 of specific hardware or when the smartphone is difficult to calibrate, should not be a bar-  
401 rier. The lack of calibration does not necessarily matter when it comes to raising awareness  
402 about noise pollution. Furthermore, in some interventions such as those presented in this  
403 article, the interest of certain measurements is based on the measurement of the difference  
404 between measured sound levels, which is normally independent of the calibration (unless the  
405 smartphone measures over sound level ranges for which it is not the most suitable).

406 In addition, the NoiseCapture application offers different display options for measurement  
407 results and various acoustic indicators. Numerous basic concepts in acoustics can thus be  
408 approached on the basis of the application from the notions of the decibel or sound frequency,  
409 to the concepts of equivalent sound pressure level over a time period or acoustic emergence.  
410 Practicing measurement with such application makes it easier to learn these concepts because  
411 participants can interact with the application to better understand the information provided.  
412 Moreover, such interventions allow to expose the health, societal and environmental impacts  
413 of noise. The bringing together of participants and acoustics professionals around a noise  
414 measurement activity also makes it possible to open up discussion on practices and activities

415 that have an impact on individual exposure, and to carry out educational and preventive  
416 work on good practices to avoid hearing trauma linked to exposure to excessive noise levels.  
417 Finally, this collective activity can open the discussion towards an awareness of the noise  
418 annoyance for others that certain activities can cause, and thus contribute socially to better  
419 living together.

420 In this respect, now that the pedagogical capacities for raising awareness about noise  
421 issues through the use of the application have been demonstrated through experience, the  
422 question arises as to how users can grasp it in the longer term. In an open format where  
423 anyone can download it, it becomes possible for local authorities to initiate projects in which  
424 groups of inhabitants are invited to download and use the application. The objective would  
425 be then to make them becoming aware of the issue of urban noise, and be part of the proposal  
426 and decision processes regarding noise. The interest is then to know to what extent this  
427 empowerment operates. These subjects are addressed in the work in progress ([Can et al.,](#)  
428 [2022](#)).

## 429 V. CONCLUSION

430 The NoiseCapture app and its ecosystem offer an interesting and attractive material to  
431 teach basics in acoustics, and more generally noise issue, both to youth and adult audiences.  
432 As outlined in this paper, the NoiseCapture team has experimented various contexts of  
433 pedagogical interventions whether in school environment or else as part of scientific events,  
434 on the own initiative of team members or at the request of teachers or public authorities.  
435 All these interventions made it possible to approach numerous basic concepts in general

436 acoustics as well as in more specific disciplines such as building, environmental acoustics or  
437 else psychoacoustics. These educational initiatives are fully in line with the open-science  
438 approach at the heart of the NoiseCapture project (codes, data, publications, etc.) since  
439 they greatly promote the dissemination of knowledge and public awareness.

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442 tutions and French regions mentioned in this article for their support in organizing these  
443 events. The authors would also like to thank all the pupils and students who, through their  
444 motivation and commitment, have also participated in the success of these operations.

445 <sup>1</sup>UMRAE website: <https://www.umrae.fr/en/>.

446 <sup>2</sup>Lab-STICC website: <https://labsticc.fr/en>.

447 <sup>3</sup>The concept of NoiseCapture Party aims at regrouping a set of participants simultaneously in order to pro-  
448 duce a participatory noise map over a delimited area ([http://noise-planet.org/noisecapture\\_party.html](http://noise-planet.org/noisecapture_party.html)).

450 <sup>4</sup>The automatic procedure with a reference smartphone makes it possible to calibrate several devices simul-  
451 taneously.

452 <sup>5</sup>A tutorial is proposed on the Noise-Planet website to exploit a huge amount of data thanks to Python or  
453 R scripts (see [https://noise-planet.org/noisecapture\\_exploit\\_data.html#raw\\_files](https://noise-planet.org/noisecapture_exploit_data.html#raw_files)).

454 <sup>6</sup><https://www.bruit.fr/entreprises/mesure-environnementales-au-smartphone-travaux-de-recherche-des-lycee>

455 <sup>7</sup>“CGénial” stands for “c’est génial” in french, which can be translated as “it’s great”.

456 <sup>8</sup><https://www.maisons-pour-la-science.org/en>

457 <sup>9</sup>The online map is available here: [https://noise-planet.org/map\\_noisecapture/noisecapture\\_party.html#16/42.7010/9.4515/AGGLOBASTIA2018](https://noise-planet.org/map_noisecapture/noisecapture_party.html#16/42.7010/9.4515/AGGLOBASTIA2018).

459 <sup>10</sup>Online map: [https://noise-planet.org/map\\_noisecapture/noisecapture\\_party.html#11/47.2251/-1.5850/FDSNTS2018](https://noise-planet.org/map_noisecapture/noisecapture_party.html#11/47.2251/-1.5850/FDSNTS2018)

461 <sup>11</sup>Online map: [https://noise-planet.org/map\\_noisecapture/noisecapture\\_party.html#16/48.5845/7.7620/FDSSTRAS2018](https://noise-planet.org/map_noisecapture/noisecapture_party.html#16/48.5845/7.7620/FDSSTRAS2018)

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