Merging Science Education, Citizen Science and General Population Noise Exposure data collection in the battle against noise pollution

Luc Dekoninck¹

Ghent University, Department of Informationtechnology, group Waves
Technologiepark Zwijnaarde 126, 9052 Ghent, Belgium

Wim Van Buggenhout

Gemeentelijk Technisch Instituut Londerzeel GTIL,
Daalkouter 30, 1840 Londerzeel

Mieke Sterken²

KU Leuven, Faculty of Science,
Science, Engineering and Technology Group Services
Celestijnenlaan 200i – box 2105, 3001 Leuven, Belgium

ABSTRACT

Science, Technology, Engineering, Mathematics in education is commonly referred to as STEM. The last decades illustrate that our society is transferring into an ever accelerating technological environment. In parallel, the general public became an important driving force in collecting citizen science data to trigger legislative pressure and impact on policy makers to accelerate the improvement of their quality of life. That practice is currently extending into the environmental impact of noise related quality of life. This publication suggests to merge those educational STEM goals, citizen science monitoring and the need for population based noise monitoring data for efficient policy support. We present an educational project as a proof-of-concept with a good potential for upscaling towards yearly measurements with different schools and classes. This approach has the potential to acquire abundant noise monitoring data and provides - by design -an unbiased population sampling dataset. This population driven involvement allows to assess real-life and long-term noise policy impact and could become a fundamental pillar in achieving the overall societal goal of improving noise related environmental quality of life.

1 INTRODUCTION

1.1 Context

Environmental noise exposure is acknowledged as a relevant component in the burden of disease. A recent update of the WHO Environmental noise guidelines summarizes the evidence and provides new dose-effect relationships based on the most recent literature [1]. Most evaluations of the exposure of the population are based on modeling. At the European level, the choice to use noise modeling is

¹ luc.dekoninck@ugent.be

² mieke.sterken@kuleuven.be, mksterken@gmail.com

standardized within the framework of the Environmental Noise Directive [2]. Within the context of the current Internet-of-Things and Smart City developments, the potential of including measured noise exposure into the ‘noise impact assessment portfolio’ is growing rapidly [3]. Integrating these noise monitoring projects into policy and into population exposure assessments is, however, challenging due to the high cost and relative low numbers of noise monitoring stations in most projects. The way forward is to build noise monitoring networks with low-cost noise monitors. This path is explored extensively in multiple projects [4, 5, 6, 7, 8, 9, 10]. A high-quality noise assessment with low-cost equipment is technically within reach [6, 11], yet, the hardware of a typical low-cost noise monitor, with a long-term qualitative microphone and wind screen, long-term logging capabilities, network connectivity and spectral analysis still costs about 200 Euros, more than sensors in similar projects for air pollution monitoring [12,13]. Moreover, the huge data volume required for noise evaluations considerably contributes to the complexity of the measurements, while the cost of the sensor deployment itself forms another significant obstacle in noise research.

In parallel with these technological developments, the general public increasingly became an important driver in collecting environmental data to trigger legislative pressure and impact on policy makers in order to improve the quality of their environment and hence reduce their own health risks. Such grassroots movements (i.e., initiatives launched by citizens), especially when executed using web-connected sensors [14], are commonly referred to as Citizen Sensing [15] and are considered a subcategory of citizen science. The latter has been defined as participatory scientific research, with lay people volunteering in science activities like data gathering, data analysis, or even all steps in the scientific process. It is often considered a novel pathway that helps scientists to gather data in a more efficient way [16, 17,18,19]. The added value, the discussions on data quality, pitfalls, remediation’s and successes are increasingly represented in literature [20, 21,22,23,24,25,0]. Within the noise context, only few citizen science projects have been implemented [e.g., 4, 9, 15,27], mainly due to the relative high cost of the relative high quality low-cost monitoring systems.

Both citizen science and data-based governance are instigated by recent exponential technological advancements. The transformation of society into a tech- and data-driven ecosystem urges our educational systems to adapt accordingly. In response to this urge, education programs in Flanders, Belgium, are increasingly aiming to orient and prepare our ‘citizens of the future’ towards technology and science related jobs. Science and Technology, Engineering, Mathematics in education is commonly referred to as STEM. During STEM-courses, students get introduced to the scientific process and improve their mathematical and technological skills, often through interdisciplinary teaching modules.

1.2. Bringing citizen science to the classroom

Citizen science projects inherently contain informal learning opportunities [14, 17]. Recently some CS-projects also started to blend with formal educational settings, receiving positive feedback from students, teachers and schools [28,29,30]

With this manuscript we present and evaluate an example case of merging noise-related CS into a high school educational program. This pilot study was initiated and facilitated by the European Erasmus+ project BRITEC: ‘Bringing Research into the Classroom’ [19]. BRITEC aims at increasing students’ engagement in STEM-activities in order to increase their STEM-literacy and skills by exploring the possibilities of citizen science in formal educational settings and hence connecting schools with the world of research, while simultaneously investigating the potentials and pitfalls of such initiatives for both the teachers and researchers involved. The project produced two guides for teachers [31,32] as well as online training (MOOC: Massive Open Online Course) that remains available online for anyone [34,35]. The core part of the project consisted of 10 pilot studies conducted with different schools from Belgium, Spain, Poland and Greece. This paper reports on one of the three selected science topics to be subjected to pilot collaborations with schools in Belgium. The results of the entire BRITEC project will be communicated in independent manuscripts. We illustrate the potential of citizen science to reduce the operational cost of population-based noise monitoring, while the primary focus is to provide an educational STEM package to secondary schools.

2. THE EDUCATIONAL PACKAGE AT A GLANCE

2.1 Initiation & context

The BRITEC project focuses on teachers from secondary schools in Europe. In Belgium, 11 teachers agreed on participating in a CS-project to be executed with their students. The BRITEC project facilitator sought and found three researchers with an interest in voluntarily engaging with students for participatory research. They each presented their research topic to the teachers who got to choose which subject would fit them best: one on meteor research, one on air quality in the classroom, and one on environmental noise monitoring (i.e., this study). Three teachers chose to participate in the latter, of which two teachers were from the same school. All three of them were teaching in the last two years of secondary school in programs with a strong focus on mathematics and technology in the curriculum. The researcher volunteered to develop an educational workflow as a blueprint for the pilot, leaving space for adaptation, fine-tuning and individual co-creation with the teachers.

The Flemish government evaluated the regional environmental noise indicators in Flanders, Belgium [36, 37]. The report recognized the need for a population-based noise monitoring indicator, opening an opportunity to test the potential of performing noise monitoring organized by teachers as one of the components in a noise related STEM project. Ghent University has an operational low-cost noise monitoring platform and a few available sensors could provide the technical component to perform the noise monitoring in a limited setup [10]. The gathered data could support the construction of a population-based noise monitoring indicator.

2.2 Sell you project with a catchy title

A citizen science project has to appeal to the schools and teachers to get selected. It requires a good title or slogan, both inspiring and triggering curiosity. For the noise monitoring citizen science project, we went for: ***“Build your own (traffic related) noise annoyance function”***. The chosen title, however, doesn’t reflect the feasibility to reach this goal within a classroom survey. The only aim of the title is to present the scientific path towards dose-response relationships and by doing so, illustrate the complexity and especially the numerous skills required to cover all aspects. Within the context of the BRITEC project, teachers with an interest of plotting citizen science projects in the classroom were recruited through social media platforms dedicated to STEM teaching in a school context. After having concisely presented (20 min) their project to a group of interested secondary school teachers during an introductory session, the scientists were connected with those teachers who chose to collaborate on their project. In our case, a total of three teachers with three class groups from two different schools joined the noise project. Each one of the class groups got four noise sensors at their disposal for use during the project execution. By coincidence, the two schools were technical secondary schools that provide the “industrial science” program. This program aims at pupils with good technical and mathematical skills in a highly technical environment and focuses explicitly less on language skills. This is not the standard trajectory to prepare for advanced educational programs but in practice, these pupils are following a full STEM educational program, established well before the STEM acronym was invented. The class groups were from the last two years of secondary school (preceding higher education), and were composed of 8 students (5th year Industrial Sciences, aged 16-17 yrs) and 7 students (6th year Industrial Sciences, aged 17-18 yrs) from the secondary school Edugo (Oostakker, Belgium) and 17 students from the 6th year Industrial Sciences 17-18 yrs) at the secondary school GTIL (Londerzeel, Belgium) where this project fitted in the courses of geography and applied physics, albeit with course materials that were adapted by the teacher to fit the educational levels of the pupils. At GTIL, a second class for the 5th year Industrial Sciences (aged 16-17 yrs) is performing the program in the second semester of 2020-2021.

2.3 The overall CS project structure

The environmental reporting performed by the Flemish government is structured according to the DPSIR-scheme (D: driving forces, P: pressure, S: state, I: impact, R: response), a framework for structuring the flow for environmental reporting and assessments, adopted by the EU Environmental Agency (<https://en.wikipedia.org/wiki/DPSIR>).

The educational project is based on this DPSIR-scheme to show the pupils that environmental reporting, science and policy are intertwined. All aspects require regular updates to integrate new knowledge in all components.

2.4 The project tasks

The project walks the students through a set of consecutive tasks. Within the context of BRITEC, the scientist explained the whole concept in the classroom, framing each of the tasks within the drivers, pressures, state, impact and response framework (DPSIR). This happened at the start of the project (but after the noise survey), during a live online session of 1.5 hours to walk the students through the project, explain the purpose of the measurements and introduced the mathematical exercises. A detailed lesson plan will be provided by the BRITEC-consortium at the end of the project (June 2021).

Table 1: Scheme of the CS educational project as presented by the scientist at the start of the study. This scheme gives a concise overview of what the pupils will learn when going through the project tasks.

Data collection	
1.	Fill in a noise annoyance survey (I)
2.	Set up a schedule to perform noise measurements at the dwellings, measure at least 48 hours, if possible, five consecutive working days or one week.
3.	Document the measurement location (geography, coordinates, ...)
4.	Count traffic for 30 minutes during rush hour, preferably while the noise monitor is active
5.	Find the (online) governmental noise maps and extract the calculated noise exposure data for your dwelling
Available noise data	
	<p>The noise monitoring data is provided in different formats</p> <ul style="list-style-type: none"> • $L_{Aeq,1sec}$ during the traffic count • $L_{Aeq,1hour}$ and $L_{Aeq,15min}$ • Statistical levels (L_{A01} to L_{A95}) for 1 hour and 15 minutes intervals • Optional: spectral (third octave) noise levels
Exercises	
	<ul style="list-style-type: none"> • Learn about L_{Aeq}, acoustical energy and summing of noise levels in dB(A) • Calculate L_{day}, $L_{evening}$, L_{night} and L_{DEN} at your dwelling • Calculate statistical levels for a $L_{Aeq,1sec}$ time series • Plot time series of statistical levels and discuss the power of visualization. Can you link the behavior of the different statistical levels to diurnal patterns in traffic? • Event detection <ul style="list-style-type: none"> ○ Build an event detection in a spreadsheet application ○ Can you link the manual traffic counts at your dwelling with the event detected in the noise time series? ○ Can you estimate the difference in noise emission of cars and trucks? • Combine the collected data in a database for the entire class and plot the results in different ways <ul style="list-style-type: none"> ○ Annoyance by measured noise levels ○ Noise map prediction by measured noise levels ○ Annoyance by traffic counts (use the difference in noise emission by vehicle type as a traffic weight by vehicle type). ○ Traffic counts and noise monitoring
Analysis and discussion	
	<ul style="list-style-type: none"> • Benefits and downsides of noise mapping • Benefits and downsides of traffic counts and noise monitoring? • When and why do certain techniques fail?

	<ul style="list-style-type: none"> • Can you link the annoyance response for the class with the noise map, the traffic counts and your own subjective annoyance response? • Do we have enough data? • The survey was the first task while it is only the fourth step in the DPSIR-scheme: why?
Conclusions	
	<ul style="list-style-type: none"> • No technique can resolve all questions • Doing science requires a large skillset • Noise monitoring adds value to the calculated noise map and the traffic counts

3. THE COLLECTED DATA

3.1 Equipment and measurement location metadata

The monitoring equipment used is the setup established within the IDEA-project. The equipment and technology is still operational despite the active use of the system since 2012 [6]. The underlying hardware have proven to be very robust. Two sets of four units were provided to the two participating schools. The teachers were introduced to the use and installation procedure of the equipment and the teachers explained that procedure independently to the pupils. A live online course given by the researcher was evaluated positively by both the teachers and the students: *“The presentation was a very interesting change of subjects for our course in Engineering, by being in contact with an external researcher during these COVID-19-times. The students acquired a very good view on what noise research encompasses and deepened their knowledge on this subject matter”* (Anonymous teacher). The collection of the measurement location metadata was done by the pupils as one of the tasks within the STEM project. They recorded the GPS coordinates of their locations of measurement, the distance from the sensor to the street, information on the position of the microphone relative to the dwelling façade and took a picture of the setting.

3.2 Noise measurements: resulting data

The presented data are limited to the 6IW at GTIL since they measured for a full week and finished the educational project by the time of the publication. The metadata results in a list of measurement sequences, performed between October, 1st till November 19th 2020. The first set of data provided are the overall noise parameters for the full measurement period (L_{Aeq} and statistical levels by hour and by 15 minutes intervals). The second set of data are the $L_{Aeq,1sec}$ for the time window within the measurement sequence when the pupils counted the traffic at their dwelling.

In Figure 1 to Figure 3, the diurnal report of three locations (MP06, MP13 and MP18) are presented. These locations are selected to express some of the variability encountered in the measurement set. The diurnal pattern of the highest noise levels L_{A01} and L_{A05} show the eventfulness, while L_{A50} and L_{A95} give insight in the occurrence of quiet periods. The results are grouped by day, evening and night in the lower right chart of each set. The distributions of the different parameters show different levels and different diurnal patterns. In Figure 4, the distributions by day, evening and night are shown for the entire class (including the teacher).

3.3 Noise survey and third party data

The Flemish government performs a region-wide standardized noise survey on a regular basis. A subset of the questions from this survey was submitted to the pupils to individually fill in. The class then collected the individual responses in a single shared spreadsheet. The spreadsheet was then extended with the results of the individual traffic counts at their dwelling. The pupils were directed towards the Flemish noise maps available online [39]. Based on their dwelling location, the corresponding L_{day} , $L_{evening}$, L_{night} and L_{den} was retrieved from the noise maps and added to the shared spreadsheet.

Figure 1: Diurnal report for pupil '06': L_{Aeq} , L_{A01} , L_{A05} , L_{A50} , L_{A95} by 15 minute interval and the distribution of the parameters by day, evening and night.

Figure 2: Diurnal report for pupil '13': L_{Aeq} , L_{A01} , L_{A05} , L_{A50} , L_{A95} by 15 minute interval and the distribution of the parameters by day, evening and night.

Figure 3: Diurnal report for pupil '18': L_{Aeq} , L_{A01} , L_{A05} , L_{A50} , L_{A95} by 15 minute interval and the distribution of the parameters by day, evening and night.

Figure 4: Diurnal report for the entire classroom (and including the teacher). One set was lost due to a technical failure of the database, the data could not be retrieved from the backup.

Figure 5: Geographical variation for the pupils' dwellings in the class.

4. ANALYSIS

Extended analysis of the data is possible but here we only present a few basic evaluations to illustrate the potential of the data collection. With only 17 students participating, the number of annoyance response surveys is evidently insufficient to draw significant conclusions from an analysis. We left it to the pupils themselves to find this out and come to this conclusion. We also let them study the differences between the measurements they did, and the measurements as deduced from the available noise map for the Flemish region.

Fifteen measurement points are compared with the values from the calculated Flemish noise map, using the provided coordinates by the pupils. An alternative would have been to use the manually retrieved noise map values from the pupils but some discrepancies between the coordinates and the manually retrieved values were detected. Five extremes with a difference above 9 dB between the empirical noise measurement and their respective noise map value are found. Evidently, deviations are expected, and investigating the deviations, explaining them and understanding the differences is the main part of the educational program (see Analysis and Discussion in Table 1).

The information on measurement location, the input in the survey and the traffic data counts can be used to explain the deviations.

Figure 6: Comparing the measurements with the noise map for the full dataset and the dataset after removing the extreme deviations.

Three pupils measured L_{den} noise levels of respectively 13, 19 and 17 dBA above the calculated L_{den} . Two pupils measured L_{den} levels 11 and 9 dBA below the calculated L_{den} .

The excess 13 dB measurement location is at five meter from the road side and the pupil reported a very low quality street surface. The 17 dBA excess can be related to railway noise; in the matching traffic counts four trains were reported in a time sequence of 30 minutes. The 19 dBA excess was reported in a low traffic street, but was measured on the first floor of the house, at two meters distance of the side of the road. The measurements, as shown in Figure 3 (MP18), suggest a very dynamic noise climate with high peak levels and very low background levels throughout the day and night. The high peak values match the reported two-meter distance to the road. In the Flanders noise map no traffic data is available for this road which explains the discrepancy. The low background levels do match the spatial configuration as the distance to main roads is large. Both the traffic count data and the description of the situation suggest low traffic intensities. The L_{Aeq} levels suggest higher noise exposure. The relative high L_{A01} values match the short distance to the source (2 m). The L_{A05} levels are about 15 dB lower than the L_{A01} values which matches sporadic high peaks but not many peaks since this would reduce the difference between L_{A01} and L_e . This points out that the pupils metadata is correct, it is a low exposure road with occasionally high peaks due to the short distance between façade and road. The reported deviation matches the

metadata and traffic counts. For these type of situations, it is normal to have no traffic data in the noise map. This is also an illustration that reporting L_{Aeq} only might lead to erroneous data when evaluating the annoyance for that situation, but this is out of the scope of this publication.

Two pupils living along busy roads measured about 10 dB less than the calculated level. The noise maps do contain local traffic data and are therefore not attributable to missing traffic data. The obvious explanation is that the available traffic information is overestimating the actual traffic dynamics. This could be a manifestation of the reduced traffic numbers during the pandemic. Especially for high density traffic roads, the amount of nocturnal traffic can be affected by the night-time travel restrictions. This will be subjected to more detailed analysis in the future.

Removing the five extremes from the class dataset results in the increase of the correlation from 0.05 to 0.52. The median deviation drops from 1.3 to -0.3 dBA, the mean deviation from 2.3 to 0.5 dBA, the third quartile range of the deviation drops from 10.3 dBA to 8.1 dBA (Fig. 6).

In the excess measurement locations, the scientist expected situations illustrating missing traffic data from the noise map, but this didn't show in this dataset unless pupil 6 is the example of this data issue. The noise maps do lack screening due to buildings, but no cases matching this situation could be identified. Another aspect is the reflection of the façade. Typically, a correction of 3 dBA is included to account for the reflection. In this dataset, it doesn't appear to be necessary to adjust for the façade reflection but this can be an effect of the pandemic situation as well. If the typical traffic is reduced throughout the entire measurement campaign, the influence of the façade reflection might be hidden. The preliminary conclusion on the quality of the noise map is positive. The challenge is to identify and predict the deviations between the measured data and the data deduced from the noise maps, by use of the metadata. The case of a dwelling exposed to railway noise does indicate that including third party data on other noise sources would be relevant. Analyzing the data as a function of the level of pandemic measures during the measurement episode is relevant. The quality of the road surface is a potential modifier. It would be interesting to add this information to the meta data.

In this class, the pupils did excellent work and after detailed analysis, the discrepancies between noise map and measurements could be explained. Erroneous reporting is difficult to avoid in any approach. However, in this educational approach, the evaluation of the data at classroom level and the guidance of the teacher offer potential to reduce and detect erroneous input.

5. DISCUSSION AND CONCLUSION

Effective STEM teaching in the classroom has a tremendous educational and vocational potential, but it also brings along challenges for teachers. First off, teachers are generally not (yet) trained to teach in the interdisciplinary context that characterizes integrated STEM teaching. Secondly, teachers may lack the affinity to the scientific practice to convincingly illustrate the relevance of STEM applications to their pupils. Studies [reference to Struyf et al. 2019, added below] have shown that the integrative aspect and the use of authentic real-world problems in STEM projects can be engaging for students, and they facilitate the teachers' implementation of a general student-centred approach. Therefore, collaborations of teachers and their class groups with scientists in a citizen science context present a promising and powerful way to bring integrated and relevant STEM projects into the classroom.

The teachers who participated in this pilot went out of their way to tailor the projects to the current curriculum goals of separate study subjects (courses). These curriculum goals (called "eindtermen" in Dutch) are imposed by the government for schools across Flanders. The participating teachers' contribution was significant and crucial, and we greatly acknowledge their input and enthusiasm.

We also congratulate the pupils for their efforts and especially for the quality of the outcomes.

The proposed educational project was positioned as a full DPSIR trajectory. The teachers decided to which extent they would include it in their educational program. In the presented case, teachers who taught different courses at school have been integrating parts of the exercises into different courses. It became, as intended by the scientist- a fully multidisciplinary approach. The technology teachers were the driving force and organized the measurement campaign, the survey and the comparison with the noise map. The exercises on noise calculation were shared between the technology (e.g. ICT, electronics, physics) classes and the mathematics classes. The response of the teachers and students was positive and requests were made to reuse the equipment and the exercise next year as well. During post-pilot interviews with the teachers, they evaluated the project as very successful and worth repeating in the coming years. The multi-course project-like structure

fitted well in the educational plan of the last year of secondary school, despite the fact that some teachers pointed to the challenge of linking several project-related aspects with the level of understanding the students had on these topics. For example, a physics topic may have been easy enough to understand for a 5th grade student, while some of mathematics in the project may have been too difficult for the 5th year students, so the teachers acted as some kind of 'filter' to adapt the different project steps into content that was well fitting the students. The pupils responded very enthusiastically on their participation in the project, but they regretted the online nature of interactions due to COVID-19 restrictions in Belgium. Similarly, both the teachers and the scientist felt that the interaction with the pupils was affected by the lack of personal contact and discussion. The first question on their mind was the influence of the pandemic on measured noise levels. The answer was simple, their efforts provided data to attempt to answer this question. In the evaluation of the project, this aspect was mentioned as a great asset: the direct application of the collected data for scientific purposes strongly increased the interest and involvement of the pupils. The second biggest asset was the multi-disciplinarity of the project; pupils became aware of the value of all types of information from their educational curriculum. Thirdly, the students were also very much inspired by meeting a 'real' scientist and getting a glimpse of what it means to 'do science' for a living, and they were motivated by the fact that they could use 'real' professional instruments to measure phenomena that were directly linked with their own personal life in their own neighborhood. Last but not least: the teachers themselves also experienced professional growth by going through a learning curve. They not only learned about new topics, but also learned through translating complex scientific concepts into teaching content that was manageable for the students.

From a scientific point of view, the data collection was very successful. Apart from introducing the pupils to the project and some teacher-scientist e-mail communication on the dataflow, the IDEA project setup showed to work very efficiently, despite a hardware problem with the database storage. The data were collected during a period with strong changes in environmental variables due to the COVID-19 pandemic. This aspect causes complications for the general use of the data for the intended research on the long term, yet evidently, the data can be analyzed to reveal certain aspects of the influence of the pandemic measures.

At the time of publication, the full analysis of the results has not been completed. Data collected this way can be used in various applications. Overall, this pilot citizen science project was highly valued by both the teachers, the pupils and the scientist, and was positively evaluated by the BRITEC project facilitator. The potential of this CS project has been submitted to the Flemish government as a potential trajectory with benefits for both the educational department and the environmental department.

Acknowledgements:

Prof. Katrien Kolenberg (KULeuven, UAntwerpen, VUB) as the Belgian project lead in the Erasmus+ project BRITEC, the Students of the Class 6IW at GTIL who provided us their measurements and metadata, the direction of GTIL for support to teacher Wim Van Buggenhout, Dr. Agata Gozdzik (Institute of Geophysics, Polish Academy of Sciences) as overall project coordinator of the BRITEC-project.

7. REFERENCES

1. World Health Organization. (2018). Environmental noise guidelines for the European region.
2. DIRECTIVE 2002/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002 relating to the assessment and management of environmental noise
3. Alías, Francesc, and Rosa Ma Alsina-Pagès. "Review of Wireless Acoustic Sensor Networks for Environmental Noise Monitoring in Smart Cities." *Journal of sensors* 2019 (2019).10
4. Maisonneuve, Nicolas, Matthias Stevens, Maria E. Niessen, Peter Hanappe, and Luc Steels. "Citizen noise pollution monitoring." (2009).
5. Botteldooren, Dick, Timothy Van Renterghem, Damiano Oldoni, Dauwe Samuel, Luc Dekoninck, Pieter Thomas, Weigang Wei et al. "The internet of sound observatories." In *Proceedings of Meetings on Acoustics ICA2013*, vol. 19, no. 1, p. 040140. Acoustical Society of America, 2013.
6. <http://idea.intec.ugent.be/en/>

7. Farrés, Júlia Camps. "Barcelona noise monitoring network." In *Proceedings of the EuroNoise*, pp. 218-220. 2015.
8. Mietlicki, Fanny, Christophe Mietlicki, and Matthieu Sineau. "An Innovative Approach for long term environmental noise measurement: RUMEUR Network in the Paris Region." In *Proceedings of the EuroNoise*. 2015.
9. Bello, Juan P., Claudio Silva, Oded Nov, R. Luke Dubois, Anish Arora, Justin Salamon, Charles Mydlarz, and Harish Doraiswamy. "Sonyc: A system for monitoring, analyzing, and mitigating urban noise pollution." *Communications of the ACM* 62, no. 2 (2019): 68-77.
10. Salvo, David, Gema Piñero, Pau Arce, and Alberto Gonzalez. "A Low-cost Wireless Acoustic Sensor Network for the Classification of Urban Sounds." In *Proceedings of the 17th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks*, pp. 49-55. 2020.
11. Picaut, Judicaël, Arnaud Can, Nicolas Fortin, Jeremy Ardouin, and Mathieu Lagrange. "Low-Cost Sensors for Urban Noise Monitoring Networks—A Literature Review." *Sensors* 20, no. 8 (2020): 2256.
12. McKercher, Grant R., Jennifer A. Salmond, and Jennifer K. Vanos. "Characteristics and applications of small, portable gaseous air pollution monitors." *Environmental Pollution* 223 (2017): 102-110.
13. Rai, Aakash C., Prashant Kumar, Francesco Pilla, Andreas N. Skouloudis, Silvana Di Sabatino, Carlo Ratti, Ansar Yasar, and David Rickerby. "End-user perspective of low-cost sensors for outdoor air pollution monitoring." *Science of The Total Environment* 607 (2017): 691-705.
14. Sheth, Amit. "Citizen Sensing, Social Signals, and Enriching Human Experience", *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences* 370 [1958], (2009): 176-197. DOI:10.1098/rsta.2011.0244.
15. Berti Suman, Anna & Marina van Geenhuizen (2020) "Not just noise monitoring:rethinking citizen sensing for risk-related problem-solving", *Journal of Environmental Planning and Management*, 63:3 (2020): 546-567. DOI: 10.1080/09640568.2019.1598852
16. Bonney, Rick, Jennifer L. Shirk, Tina B. Phillips, Andrea Wiggins, Heidi L. Ballard, Abraham J. Miller-Rushing, and Julia K. Parrish. "Next steps for citizen science." *Science* 343, no. 6178 (2014): 1436-1437.
17. Conrad, Cathy C., and Krista G. Hilchey. "A review of citizen science and community-based environmental monitoring: issues and opportunities." *Environmental monitoring and assessment* 176, no. 1 (2011): 273-291.
18. Bonney, Rick, Caren B. Cooper, Janis Dickinson, Steve Kelling, Tina Phillips, Kenneth V. Rosenberg, and Jennifer Shirk. "Citizen science: a developing tool for expanding science knowledge and scientific literacy." *BioScience* 59, no. 11 (2009): 977-984.
19. Newman, Greg, Andrea Wiggins, Alycia Crall, Eric Graham, Sarah Newman, and Kevin Crowston. "The future of citizen science: emerging technologies and shifting paradigms." *Frontiers in Ecology and the Environment* 10, no. 6 (2012): 298-304.
20. Ottinger, Gwen. "Buckets of resistance: Standards and the effectiveness of citizen science." *Science, Technology, & Human Values* 35, no. 2 (2010): 244-270.
21. Aceves-Bueno E., Adeleye A.S., Feraud M., Huang Y., Tao M., Yang Y., Anderson S.E. 2017. The accuracy of Citizen Science Data: A quantitative review. *Bulletin of the Ecological Society of America*, vol. 98 (4), 278-290.
22. Cox J., Oh E.Y., Simmons B., Lintott C., Masters K., Graham G., Greenhill A., Holmes K. 2015. How is success defined and measured in online citizen science? A case study of Zooniverse projects. *Computing in Science and Engineering*, vol. 17 (4), p. 28-41.
23. Riesch, H. & Potter, C. (2013). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*, 0963662513497324.
24. Westreicher F., Cieslinski M., Ernst M., Frigerio D., Heinisch B., Hübner T., Rüdissler J. 2020. Recognizing failures in citizen science projects: Lessons learned. *Proceedings of the Austrian*

- Citizen Science Conference ACSC 2020. 14-16 September 2020. Vienna, Austria. 9 pp.
<https://pos.sissa.it/393/007/pdf>
25. Kelling, Steve, Alison Johnston, Aletta Bonn, Daniel Fink, Viviana Ruiz-Gutierrez, Rick Bonney, Miguel Fernandez, Wesley M. Hochachka, Romain Julliard, Roland Kraemer, Robert Guralnick. "Improving Citizen Science Data for Monitoring Biodiversity". *BioScience* 69 (2019): 170-179.
 26. Brossard, Dominique, Bruce Lewenstein, and Rick Bonney. "Scientific knowledge and attitude change: The impact of a citizen science project." *International Journal of Science Education* 27, no. 9 (2005): 1099-1121.
 27. Berti Suman, Anna (2018) "Challenging risk governance patterns through citizensensing: the Schiphol Airport case", *International Review of Law, Computers & Technology*, 32:1 (2018): 155-173. DOI: 10.1080/13600869.2018.1429186
 28. Aivelo Tuomas., Suvi Huovelin. "Combining formal education and citizen science: a case study on students' perceptions of learning and interest in an urban rat project". *Environmental education research*, vol. 26 [3]. (2020): 324-340.
 29. Gray Steven A., Kristina Nicosia, Rebecca C. Jordan. "Lessons learned from citizen science in the classroom." *Democracy & Education*, vol. 20 [2]. (2012): 1-5.
 30. Harlin John, Laure Kloetzer, Dan Patton, Chris Leonhard, Leysin American School high school students. "Turning students into citizen scientists." In: Hecker Susanne, Muki Haklay, Anne Bowser, Zen Makuch, Johannes Vogel, Aletta Bonn: "Citizen Science: Innovation in Open Science, Society and Policy." (2018) UCL Press, London.
<https://doi.org/10.14324/111.9781787352339>.
 31. Adina Nistor, Jose Clemente-Gallardo, T Angelopoulos, Karolina Chodzinska, Maria Clemente-Gallardo, Agata Gozdzik, Antonio Gras-Velazquez, Antonija Grizelj, Katrien Kolenberg, Despoina Mitropoulou, Alexia D Micallef Gatt, E Tasiopoulou, A Brunello, P Echard, V Arvaniti, S Carroll, N Cindea, N Diamantopoulos, N Duquenne, S Edrissy, E Ferguson, L Galani, K Glezou, A Kameas, H Kirmaci, I Koliakou, E Konomi, E Kontopidi, S Kulic, I Lefkos, G Nikolettakis, E Siotou, A Simac, F Sormani, M Tramonti, M Tsapara, E Tsourlidaki, M Vojinovic. "Bringing Research into the Classroom – The Citizen Science approach in schools." *Scientix Observatory Report* (2019), 37 pp., European Schoolnet, Brussels.
 32. Gozdzik Agata, Dagmara Bozek, Karolina Chodzinska, Jesus Clemente, Maria Clemente, Alexia Micallef Gatt, Antonija Grizelj, Despoina Mitropoulou, Anita Simac, Franca Sormani, Mieke Sterken. "BRITEC citizen science toolkit". Erasmus+ project report (2021), 52. pp.
 33. Zipf, Lucy, Richard B. Primack, and Matthew Rothendler. "Citizen scientists and university students monitor noise pollution in cities and protected areas with smartphones." *PloS one* 15, no. 9 (2020): e0236785.
 34. The BRITEC project: <https://britec.igf.edu.pl/>
 35. BRITEC. "MOOC: A roadmap to citizen science education" (2021): <https://www.europeanschoolnetacademy.eu/courses/course-v1:BRITEC+CitizenScience+2021/about>
 36. Geluidshinder – Evaluatie van de MIRA indicatorset (in Dutch): e
 37. Dekoninck, Luc, and Dick Botteldooren. "Regional environmental noise indicators: SWOT analysis and future developments." In *e-Forum Acusticum 2020*, pp. 1663-1665. 2020.
 38. <https://en.wikipedia.org/wiki/DPSIR>
 39. <http://www.geopunt.be/catalogus/datasetfolder/687d2575-a53a-4530-94a5-be942ee01e00>
 40. Struyf, Annemie; Haydée De Loof; Jelle Boeve-de Pauw; Peter Van Petegem: "Students' engagement in different STEM learning environments: integrated STEM education as promising practice?" *International Journal of Science Education* 41 [10] (2019): 1387-1407, DOI: [10.1080/09500693.2019.1607983](https://doi.org/10.1080/09500693.2019.1607983)