Sonification of nitrogen dioxide and carbon monoxide measurements

Subjects and topics:

- Music: Pitch, Intervals, Melodic sequences, Rhythm
- Environmental Studies: The atmosphere
- Physics: Gas, Oxygen.
- Mathematics: Data Analysis and Statistics.
- Information and Communication Technologies: Digital Literacy, Data Sonification, Multimedia.
- Arts: Audio representations and reproductions.

Duration: 2 weeks

Grade level: 5th - 6th, (11-12 years old)

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Summary

Computer Science teachers, in collaboration with students, constructed a gas meter using an Arduino board and sensors to measure NO2 and CO, i.e. nitrogen dioxide and carbon monoxide. As part of the activity, the children learned basic concepts about sensors (how they collect data, what calibration means, and why the same measurement conditions are important), as well as how Arduino reads the values and stores or displays them. At the same time, they discussed safety issues and the proper use of the equipment, took test measurements on school grounds, and recorded the initial readings in tables to confirm that the device was working reliably.

Next, the students, together with their physics teachers, visited various outdoor areas and took measurements at locations with different characteristics, such as near busy roads, in parks, in more open spaces, or near parking lots. For each measurement, they recorded information such as location, time, weather conditions, and any factors that could affect the values. When they gathered the results, they commented on them, identified differences, and tried to interpret possible causes of the changes. Finally, in their computer science class, they created a data processing program: organized the measurements, performed calculations (e.g., average, maximum/minimum value), created graphs, and converted the values into sound (sonification) so that changes in gas concentrations could be heard. In this way, they linked construction, the experimental process, and data analysis into a comprehensive project with clear scientific and educational value.

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The SoundScapes scenario with instructions for students

1. FEEL

In the FEEL phase, the goal is for students to "get into" the topic in an experiential way, connect the project to their everyday lives, and formulate their own initial questions to explore. The process begins with an engaging stimulus: we show a short video/images about air pollution and air quality in the city or at school, or we conduct a small "surprise experiment" outside the entrance (e.g. we observe the traffic, the smells, the dust, and discuss what might be in the air that we cannot see). This is followed by a 10-15 minute discussion with questions such as: "Where do you think the air is 'cleaner'?" "When do we feel like we have trouble breathing?", "How can pollution affect our health or our concentration in class?" We record the answers on a board/paper without judging them, so that the students' experiences and concerns are visible.

*Next, we move on to co-creation. The students are divided into small groups and receive a simple "idea sheet" with three fields: **(a) What do we want to learn? (scientific question), (b) Where/when will we measure it? (points and conditions), (c) How will we present it? (data/sound/image)**. Each group proposes 2–3 questions (e.g., "Is there a difference between the air near the road and in the park?", "Does the time of day affect the values?", " What happens after rain or wind?"), as well as possible measurement points around the school. Then there is a "gallery walk": the teams stick their ideas on the wall, everyone walks by, reads them, and puts stickers/votes on the proposals that interest them most. Based on the votes, the class selects 2-4 key research questions and agrees on an initial action plan (routes, points, times). Finally, we conclude the phase with a clear definition of "what we will consider a success" (e.g., collecting reliable measurements, processing them correctly, converting them into sound so we can "hear" the air quality) and assigning roles (measurement team, data recording team, programming/sound team, presentation team). This way, students feel that their work is directly relevant, they have a say in decisions, and they are ready to move on to the next phase, where they will imagine solutions and ways to utilize the results.*

<u>Results of this phase:</u>

By the end of implementation, you can add the results of this phase here, including photos, moments of inspiration, quotes from students and other people involved, etc. This may inspire others to design projects as amazing as yours.

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2. IMAGINE

In the IMAGINE phase, students utilize what they have learned so far (sensors, measurements, data, basic concepts of pollution) and move from "what is happening" to "what can we do about it." The process begins with a brief inspirational introduction: we listen to 2-3 examples of sonification (e.g., converting numbers into notes, changing volume/rhythm according to value, using different instruments for different gases) and discuss what we understand from the sound alone. Then, we set a common framework: "Our goal is to make the data audible so that it becomes more understandable and can be communicated to others." We present the students with "rules of the game" so that they can work independently: each idea must answer (a) what data it uses (NO, CO, time, location), (b) how it converts it into sound (pitch/intensity/rhythm/timbre), (c) what message it wants to convey to the audience.

The students then work in groups and brainstorm for 10 minutes: they write down as many ideas as they can without criticism. To help them, we give them "idea cards" with options:

Forms of sonification: melody (values become notes), rhythm (values become beats/tempo), intensity (as the gas increases, the sound becomes louder), timbre (different instruments for NO and CO), sound effects/environment (e.g., street noise when values are high).
Data organization: by measurement point, by time, comparison of 2 areas, route map, average/maximum, "alarm" when limit is exceeded.
Audience/purpose: classmates, parents, community, visually impaired people, awareness campaign on air quality around the school.

Once many ideas have been generated, we move on to selection and refinement. Each group selects 1-2 of its strongest proposals and turns them into a "mini-plan" (one A4 sheet) that includes: title, what data it uses, how it will sound, what it wants to show, and what it needs technically (software, audio libraries, file format). Then each team gives a 2-minute presentation and the others ask targeted questions: "Will anyone understand the difference between NO and CO?", "What will it sound like when the values are low/high?", "How will you explain to the listener what the sound means?" Based on feedback and voting, the final direction is chosen, or elements from more groups are combined.

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The phase concludes with the extroversion/social dimension: students imagine where the result can be used (e.g., presentation at a school event, creation of an audio "map" of the neighborhood, posting on a school website/radio station, informing the municipality or parents' association). They write down a short message of intent, such as: "With our sonification, we want to..." and define the next practical step (what data will be used, which audio scenario will be implemented first). In this way, students move on from the IMAGINE phase with a clear idea, motivation, and a common plan that can be implemented in the next phase of implementation.

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3. CREATE

In the CREATE phase, students transform their ideas into a functional project: they organize their work, select materials/software, implement the sonification, and document the process. We start with a common "project map" on the board: What are we going to make? (goal), With what? (materials/tools), How? (steps), Who? (roles), When? (time). The students are divided into working groups and each group completes a short 1-page plan describing: (a) what data they will use (NO, CO, location, time), (b) what form of sonification they will produce (pitch, intensity, rhythm, different instruments), (c) what the final deliverable will be (sound file, presentation, graph + sound). At the same time, we draw up a list of materials and tools: Arduino/sensors, cables, power supply, laptop/PC, data processing software (e.g., spreadsheet or Python/Scratch), sound production program or sound libraries, recording sheets, and a shared file storage folder.

To ensure equal opportunities for participation, we assign rotating roles (so that no one is stuck with just one job):

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1. Device/measurement team (Arduino control, correct connection, stable measurement conditions),

2. Recording/documentation team (logbook, photos, notes on place-time-weather),

3. Data group (cleaning values, tables, averages, identifying extreme values),

4. Sonification / programming group (rules for converting data to sound, creating files),

5. Presentation team (narration, diagrams, message to audience).

Every 1–2 lessons, the roles change so that everyone gets to do technical and creative tasks. At the same time, we set clear rules for cooperation: everyone speaks, everyone listens, decisions are recorded, and at the end of the hour, each team delivers a short summary of "what we did today – what remains to be done."

Implementation is achieved in steps—small goals (small victories): first we ensure that the measurements are stored correctly, then we organize the data in a table, then we try a simple sonification (e.g., 10 values → 10 notes), and finally we move on to more complex options (different instruments for NO/CO, change of rhythm per point, "alarm" at high values). We encourage students to work with trial and error and improvement: we keep an "error log" where they write down what did not work, why they think it happened, and what they changed. We emphasize that failure is part of the process and that every mistake is a given that leads us to a better solution. At the end of the phase, each team presents a first functional prototype (even if simple) and receives feedback to improve it in the next phase.

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4. SHARE

Students present their work to a real audience and turn their efforts into a message to the community. We start by defining the target audience: the groups discuss and choose who they want to address (e.g., students from other classes, parents, teachers, the local

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community/municipality, people with visual impairments). To decide, they answer three simple questions: "Who are we talking to?", "What do we want them to understand/feel?", "What do we want them to do after the presentation?" (e.g., pay attention to pollution around the school, suggest changes, participate in actions). Then, they organize their material based on a common narrative structure: the problem → how we measured it → what we found → how we made it audible → what this means for us/the community. This way, everyone follows a clear line and the presentation is understandable even to people who are not familiar with technical details.*

The students then prepare the presentation deliverables, choosing a format appropriate for the audience: slides, poster/infographic, short video, audio clip, or "demonstration stations" (a table with Arduino, measurement samples, headphones, and the sonification program). Each team takes on a specific part: one team creates the diagrams and tables, another prepares the audio file/playlist (with titles and brief explanations of what the audience is listening to), another writes the texts/captions, and another organizes the presentation rehearsal (timer, who speaks when, what we show). We give instructions to make the presentation accessible and clear: few words per slide, legible graphs, clear connection between "value → sound," and a short "listening guide" (e.g., "as CO rises, the sound becomes louder/sharper"). Finally, we allow time for reflection: after the presentation, students fill out a short sheet with the questions "What went well?", "What did we find difficult to do?", "What would we change if we did it again?", "What did we learn about data, sound, and collaboration?" We conclude with a group discussion and collect ideas for improvement (e.g., more measurement points, better visualization, more "understandable" sonification, collaboration with organizations). Thus, the SHARE phase becomes not only a presentation, but also a completion of learning with a meaningful impact.

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