CO2 Tracker: a Platform for Improving the Awareness of Carbon Dioxide Levels in an Urban Environment

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Abstract

CO_2 tracker is a digital platform that raises awareness about the concentration of carbon dioxide, its relation to the territory, and the causes that can increase it. The platform has been designed to gather carbon dioxide values and other environmental variables along a path and visualize them in real time. Citizens using the platform are challenged to find an alternative route, characterized by lower CO_2 levels, for returning to the initial location. Thanks to this gamification mechanism, the citizens are pushed to think about the possible causes of higher CO_2 values and test the hypotheses in the field, selecting alternative paths characterized by different environmental conditions, in terms of built environment, traffic, flows of persons, and other factors. A three-day workshop was held to evaluate the platform with 26 master's students. The evaluation gave interesting results about different dimensions, including effectiveness, engagement, and impact on citizens' behavior.

CCS Concepts

• **Human-centered computing → Empirical studies in visualization**; • **Social and professional topics → Sustainability**.

Keywords

behavior change, citizen science, data visualization, design, environmental data, evaluation, gamification

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1 Introduction

Global warming is today one of the most significant challenges for the planet. Carbon dioxide (CO_2) is an important heat-trapping gas that raises temperatures, impacting life. The digital platform presented in this paper intends to raise awareness about the concentration of this gas and its relation to human activities on the territory, with the ultimate goal of influencing the collective consciousness and leading to a behavioral change.

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To achieve this aim, the platform permits gathering data along a path, taking advantage of prototypical CO_2 mobile trackers designed and implemented by students and researchers of Ca' Foscari University of Venice. On top of the technical architecture of the platform, an interactive game, requiring participants to identify the urban routes with the lowest CO_2 emissions level, has been created. The game has been designed for citizens, with an easy and engaging interface to improve their comprehension of the subject. The digital platform also has additional features, like a collaborative data repository that can be accessed with different filtering possibilities for further use.

After the design, a three-day workshop was organized to test the system and give an answer to the following research questions:

Q1 Can CO_2 geolocalized data be gathered and presented effectively and engagingly to citizens who are not experts in environmental issues?
Q2 Can the gathering experience with the CO_2 tracker effectively improve citizens' awareness about the relationship between carbon dioxide levels and the environment?
Q3 Can the gathering experience with the CO_2 tracker be helpful to change the citizens' habits during their daily paths?

2 Related works

Several observatories on Earth gather regularly CO_2 values. According to data recorded in the famous Mauna Loa Observatory (Hawaii) since 1960, the concentration of CO_2 in the atmosphere has increased from an average value just below 320 ppm to 424 ppm in 2024. CO_2 release in the atmosphere is one of the causes of the so-called greenhouse effect and endangers the existence of the ozone layer, a gas that protects the Earth from UV rays coming from the Sun. Besides, while CO_2 doesn't have generally dramatic effects on human health outdoors, higher concentrations of this gas in urban areas can sometimes be associated with elevated levels of other harmful pollutants produced during combustion (e.g., NO_2, CO, PM2.5/PM10, SO_2, etc.) or other processes.

While awareness about these issues is increasing, it is insufficient among average citizens. Gathering CO_2 data is the first step for improving the awareness of carbon dioxide concentration. Geolocalization of CO_2 sensors is often a relevant parameter for data gathering, and, usually, we can identify two different situations:

- *fixed stations*: data are collected in single or multiple locations over time, as it happens for Mauna Loa and other observatories on the Earth;
- *mobile stations*: data are collected along a path in a temporal sequence

A key issue for understanding the meaning of the gathered data is using a proper representation. Data visualization [16] techniques offer different opportunities for representing data, and their choice can vary according to the specific scenario. While most representations are visual, technological advances also offer the chance to create audio [31] or physical [15] [26] representations. Despite technical difficulties, in recent years, some interesting experimentation has also been carried out [4] with the sense of smell. The spatial and temporal distribution of the gathered data can lead to different types of representations. For example, in the case of data collected by a network of fixed stations, it can be helpful to have synchronic representations layered on a geographical map or time-based representations.

In this work, the focus of interest is on the representation of data along a path collected in a temporal sequence. Numerous examples of this type of representation for various contexts are available in the literature. Path visualization is most frequently used in road traffic. A very famous example can be found in Google Maps [11], which depicts the traffic intensity along a route using colors. Another example can be found in Goldsberry [10], who examines traffic maps from four cities in the United States. While color coding and the traffic light convention (i.e., red-yellow-green) characterize most representations, Goldsberry suggests that additional information can be mapped to color brightness or line size. Alternative examples of path visualization on maps have been proposed by the Minnesota Department of Transportation. In the *Bicycle and Pedestrian Data Collection Manual* [22], data is collected by a group of sensors counting the number of pedestrians and bikes passing through some selected paths. The data visualization takes advantage of two main representations: circles with different radii placed in correspondence with the sensors, and trails to visualize the flows of bikes and pedestrians. The red-yellow-green color scheme, used in this manual for representing quantities of persons and bikes, is also exploited in Alam et al. [1], who use traffic data to infer and represent the level of CO_2 emissions in Dublin. *Data walking* [13] is a research project related to data collected along a path, that experiments with different types of representations (visual, auditory, and physical) related to environmental and social data gathered while walking along a route [14]. While many representations of the *Data walking* project take advantage of a 2D map, in some cases, a pseudo-3D representation is used to associate other variables to the third dimension. In other cases, map details are hidden, emphasizing the path's shape. In another solution, the path's shape is hidden, and the gathered data are represented as physical columns of textured cylinders of different sizes. In our work, after considering the existing solutions, the target audience, and the devices to use during the gathering sessions, we chose to represent the path through 2D representations and the most popular red-yellow-green color scheme. The complementary use of a detailed map was also deemed necessary because the game required making decisions based on the awareness of different types of environments to walk (eg, green/blue zones vs residential or industrial zones).

The concept of walkability, explained in [9] and [18], can be defined as the possibility of a particular path or urban area to be walked by. Their accessibility can be measured by considering many factors, which include security, barrier-free access, health, and others. In Lwin et al. [19], walkability is calculated considering the distance of pedestrian paths from green areas. The application developed by these researchers permits comparing the greenest path with the shortest route in Tsukuba City, Japan. In our work, the concept of walkability has played a pivotal role in designing the user experience. The game involves discovering better routes in relation to CO_2 levels. We can refer to them as more walkable paths, compared to the initial journeys.

Gamification can be defined as using game design elements in non-game contexts to engage participants and encourage the adoption of desired behaviors. A substantial body of research demonstrates gamification's effectiveness in enhancing user learning and engagement. Wilson et al. [30] promote the educational use of gamification, sharing the results of a study that shows quantifiable benefits for online learning. Another study [23], conducted by O'Donovan et al., provides an excellent illustration of the efficacy of gamification in a computer game design class. A common approach is the use of simple tasks or awards, as exemplified by [6], [7], and [12]. Another method of gamification concerns using formalised games as pedagogical tools for students [21]. There are many additional examples in which gamification techniques have been demonstrated to enhance engagement and comprehension in various subject areas, including environmental studies. *Play&Go* [20] is a mobile platform promoting behavior change towards sustainable mobility, using challenges and prizes. The player can track his score through the amount of *green leaves* points obtained using the most green transport, such as walking, biking, bus, or car-sharing. The latter study is strongly related to our work because it uses a mobile app to promote behavior change, a gamification approach, and challenges players to find alternatives in everyday activities. However, our study also encourages citizens to reflect on the factors contributing to high CO_2 emissions in an urban setting.

Citizen science involves volunteers and scientists collaborating on research activities to generate new evidence-based knowledge. The level of citizen participation defines various types of citizen science projects. These projects can range from collecting and sharing data and observations over geographical areas or periods, to online solutions where people help process large amounts of data, for example by classifying images or transcribing text. Bonney et al. [2] outline that, each year, more people are likely to participate in scientific investigation through citizen science projects. These projects are becoming increasingly widespread, accessible, enjoyable, and rewarding. These are the goals that our project aims to achieve. Citizen science can increase understanding of scientific content and provide insights into the process and nature of science. There is also growing evidence of the potential for citizen science to profoundly impact the lives of the involved citizens.

One of the earliest and most widely adopted forms of citizen science is observing and monitoring the fauna. One of the most frequently referenced projects is the North American Breeding Bird Survey (BBS) [28]. This project represents the primary source of critical quantitative data for the evaluation of the status of continental bird species. Ward-Paige et al. [29] describe another project related to the monitoring of animal species. The project involved recruiting scuba divers who conducted over 83,000 dives to monitor the presence of sharks in the Caribbean. The findings documented a decline in 14 species of shark over 15 years. In the context of environmental monitoring, citizen science represents a valuable tool for the observation and documentation of environmental conditions and changes. One notable initiative in this field is *Earthwatch* [8], which was established in 1971 to address global environmental issues by implementing a proven citizen science and community engagement model. Lemmens [17] focuses on the design of apps targeted to citizen science, outlining the need for easy-to-use interfaces and gamification mechanisms to increase the citizens' motivation. Citizen science is a crucial component of our project. Using our digital platform, data can be collected through an easy interface by citizens who don't have a background in environmental studies, using mobile stations after an initial short briefing. The citizens then interpret the collected data using the web application accessible from their phones. Besides, the data collected by the citizens becomes part of a repository that scientists can access for further use.

The following sections will present a detailed description of the digital platform, the design of the gaming experience, and its evaluation with 26 students of Ca' Foscari University of Venice.

3 The Mobile Platform

The CO_2 tracker project is part of a larger research activity, held in collaboration with environmental scientists of the same University department, to monitor the values of CO_2 and other environmental variables on the coasts of our region. The research activity started in the context of an EU project [3] aimed at reconstructing coastal dunes, repopulating them with local plants, and monitoring the impact of this activity on CO_2 levels through a set of fixed stations. Because no off-the-shelf device was available for the monitoring activity, the stations were designed and implemented in-house [25]. The project then evolved by moving to an urban scenario and, using the accumulated expertise, building mobile stations to add flexibility to the monitoring activity.

Since the start, the research activity has had twofold goals: collecting geolocalized data for further analysis by scientists and involving simple citizens, to make them aware of the issues related to CO_2 and its relation to different environmental factors. The CO_2 tracker project complies with this research direction, providing a flexible way to collect environmental data along a path and store it, both for improving the citizens' awareness and creating a data repository for scientists.

From a technical point of view, the mobile stations were created with a lightweight and compact design to ease transportation. As shown in Fig. 1, the stations' core is a Raspberry Pi Zero [27], a low-cost mini computer built on the ARM architecture that runs Linux as its operating system. The Raspberry Pi board is connected to other hardware components, including the CO_2 sensor, temperature and humidity sensors, and a GPS module. A USB modem grants Internet connectivity for sending data to the online database, hosted in a virtual machine. The same virtual machine hosts the web application that citizens can access to play the game, using a standard web browser on their smartphone. While interaction during the gathering sessions happens mainly through the web application, the mobile station also features a minimal interface with a button and a small RGB LCD screen (see Fig. 6). These components are used for booting or halting the station, providing feedback about the correct functioning of the sensors, and displaying current CO_2/temperature/humidity values. The availability of this interface

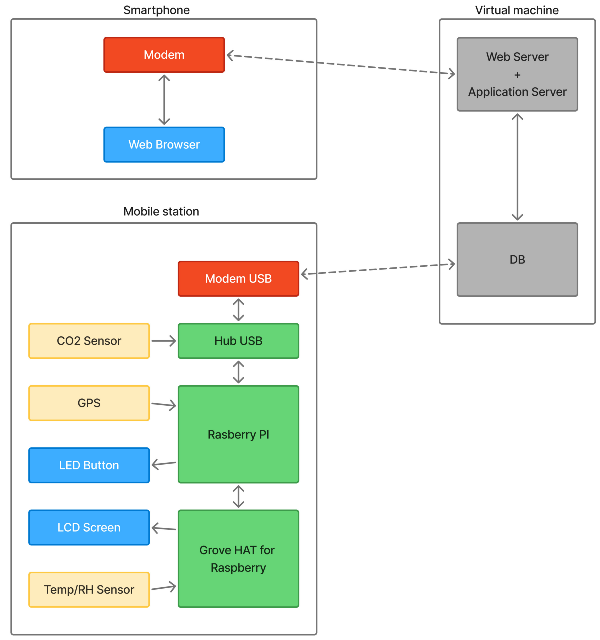

Figure 1: Components of the mobile platform.

also makes it possible to use the station for simple measurements without the need for a connected smartphone.

4 CO_2 Tracker Interface

The CO_2 tracker features an easy-to-use interface, created using responsive web design principles and accessible from a standard web browser. The initial dashboard, whose screenshot can be seen in Fig. 2-left, offers access to three main functionalities:

- *CO_2 tracker game*: the interface to manage all the phases of the gaming experience;
- *Gathering session*: a subset of the gaming experience, limited to the gathering of data along a path, without any gamification;
- *Statistics*: The repository of all the sessions recorded in the platform, with different options for filtering, visualizing, and downloading data for further analyses.

The rest of the section will be focused mainly on the first and third functionality.

4.1 CO_2 Tracker Game

After selecting the gaming session, the user is asked to type an acronym that will identify her and select the mobile station that will be used for the session (i.e., three mobile stations have been built for the experimentation). The data gathering session will start after the confirmation of this data, and the interface will change to the layout shown in Fig. 2-right, displaying the values collected by the selected station. In the current configuration, measurements are updated every 10 seconds. The interface also offers the option to add qualitative geolocalized observations by pressing a dedicated button, but the discussion of this functionality is outside the scope of this paper.

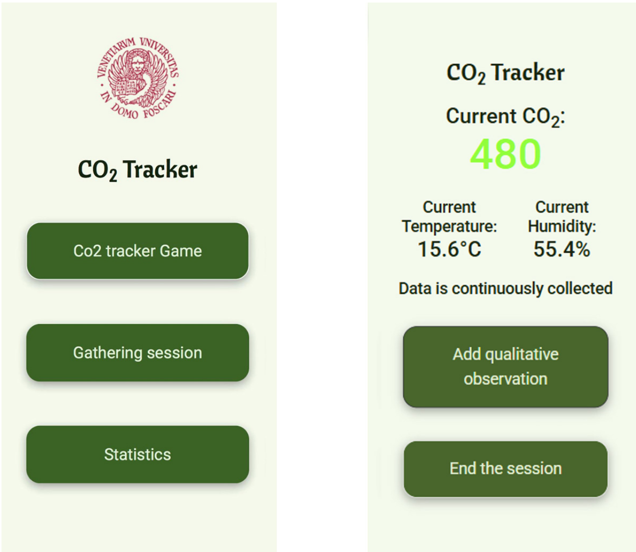

Figure 2: CO_2 tracker: the dashboard and the interface during the data gathering phase.

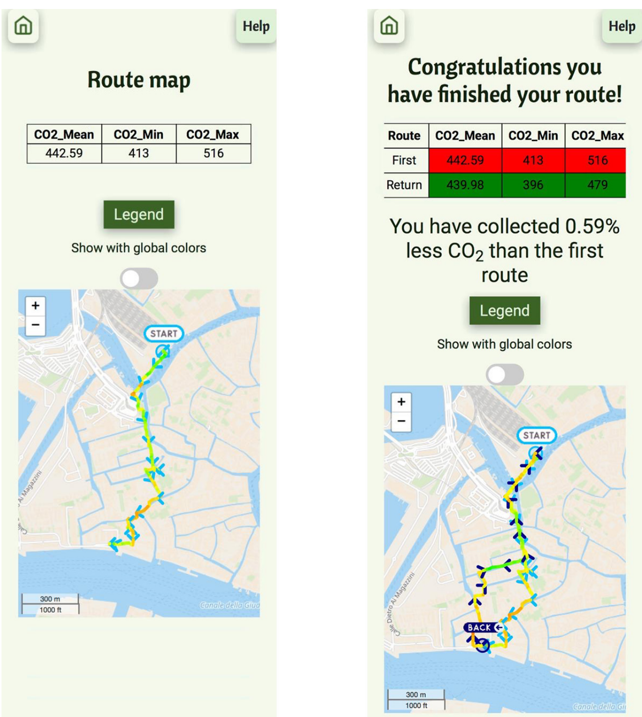

Figure 3: The initial route of the gaming session and the comparison with the back route at the end of the session.

After reaching the established destination, the user will end the first gathering session by pressing the button at the bottom of the interface. As a result, the user will be presented with a map showing the walked route (see Fig. 3-left), whose colors map the values of

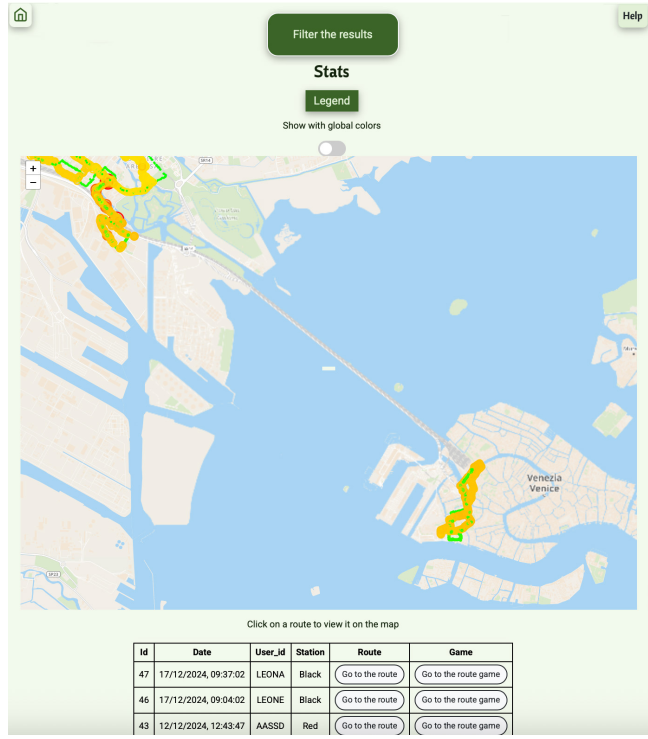

Figure 4: The map available in the Statistics section of the platform, followed by the list of the data gathering sessions.

CO_2, using the aforementioned red-yellow-green convention. To outline differences, the color gradient is optimized using red for the maximum concentration and green for the minimum concentration of CO_2. But an alternative gradient, related to an absolute scale, can be shown by selecting the switch *Show with global colors*, available at the top of the map. A simple table above the map summarizes the max, min, and mean values of CO_2 along the path. These values can be considered as the walkability index of the path.

Then the user will have the chance to explore the map using the usual panning and zooming operations to gain more insights and decide on a strategy for returning to the initial location, minimizing the values of CO_2 collected along the path.

In the second part of the session, the user will re-enter the data gathering interface (Fig. 2-right) and walk on the way back, using the alternative route. After completing the path, the user will be presented with a map (see Fig. 3-right), showing the first and return routes, and a table showing max, min, and mean values. Red areas on the table will outline which values are higher, comparing the two walks. Overall, this interface will not only show success or failure, but will also allow the user to check the correctness of the hypotheses made for minimizing CO_2 values, investigating the details of each part of the walk.

4.2 CO_2 Tracker Statistics

The interface displayed in Fig. 4 permits checking the results of all the gathering sessions, which can be filtered by period, user acronym, and mobile station used during the gathering session.

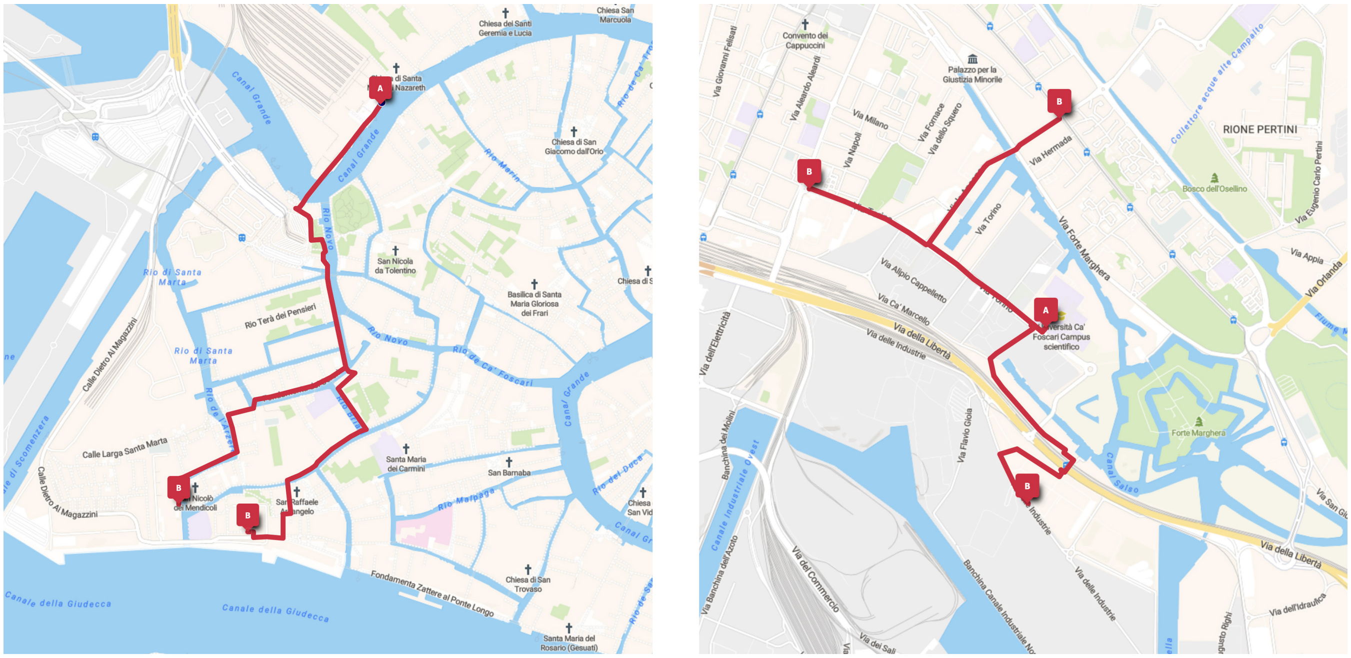

Figure 5: Routes in Venice and mainland: labels A identify the starting locations, while labels B identify the end of the initial path for each route.

The colors' gradient (red for the max value and green for the min value) can be optimized for the values collected in the filtered sessions, or those collected in all the gathering sessions. The latter modality, which can be activated by selecting the switch on the top of the map, can be used when it is more important to have a homogeneous representation for all the situations rather than emphasizing differences for specific datasets. The list below the map representation offers the chance to select a single route or, if the route is part of a gaming session, both the initial and return path of the same session. All the data can be downloaded as .csv files for further analysis. The availability of this interface represents not only an additional opportunity for citizens to improve their awareness about CO_2 distribution, but also a tool for scientists that can use it in the context of citizens' science projects.

5 Evaluation Study

To evaluate the digital platform, a workshop was organized involving 26 students enrolled in the master's program in computer science at Ca' Foscari University of Venice. The age of the participants (14 males and 12 females) ranged from 23 to 38 years, with a mean of slightly over 26 years. Most respondents declared a medium level of awareness about the impact of CO_2. None of the participants had specific training in environmental sciences.

The students were organized into nine small teams, and they participated independently in the gaming sessions. The teams could select one of the five proposed paths in Venice and the mainland (see Fig. 5), starting respectively from the train station and one of the University sites. Each path had a similar length, about 2 km. Each route had a different destination and a path to be followed strictly for the initial route. Each group was responsible for deciding the alternative path for returning to the initial location, to lower the values of CO_2 recorded during the initial route. We established that the competition winner would have been the group capable of obtaining the best performance, in terms of improved walkability (i.e., lower CO_2 values).

A precise protocol was established for the gaming session, including the following steps:

- initial briefing with the description of the goal of the gaming experience;
- boot of the mobile station and access to the web application (see Fig. 6);
- start of the walk session towards the selected destination (see Fig. 7); each group was required to follow strictly the assigned route; for this reason, one of the group members was in charge of guiding the group, using a Google Map shared by the workshop supervisors; the group members were also asked to check regularly CO_2 values while walking;
- stop of data gathering after having reached the planned destination;
- collaborative exam of the results achieved, checking the map and the numerical values of CO_2 collected along the path;
- collaborative exam of alternative routes for walking back to the initial location, to lower CO_2 levels; groups were told that they could use the digital map for exploring solutions; the only constraint was that the return route could be up to 50% in length of the initial route;
- start of the return route;
- stop of data gathering after having returned to the initial location;

Figure 6: The mobile station and the smartphone connected to the web application display the same data on their visual interfaces.

Figure 7: The members of a group start their walk through Venice.

- collaborative exam of the results, comparing the two routes on the map and checking the related CO_2 values;
- filling of a survey about the experience done; each group member was asked to complete the survey independently.

The survey was organized in four different sections, including:

- demographic information;
- user engagement, defined through four parameters (i.e., focused attention, perceived usability, aesthetic appeal, and reward) and analyzed through the UES short form described in [24];
- representation of data along the path;
- impact of the gaming experience on participants' awareness and behavior.

The survey included open and closed questions based on a 5-point Likert scale. The sessions, organized in the wintertime, were completed in three days, exploring all the proposed paths, with a limited number of groups playing in parallel on different paths, to have the chance to support them during the session in the case of technical issues. Participants could communicate with the workshop supervisors through text messages in case of trouble (i.e., in one case, one of the stations froze after a few meters, and it was necessary to restart the session). Still, we were ready to reach the groups in the case of huge technical problems (which didn't happen).

6 Questions and Results of the Evaluation Study

This section will present all the questions and related answers.

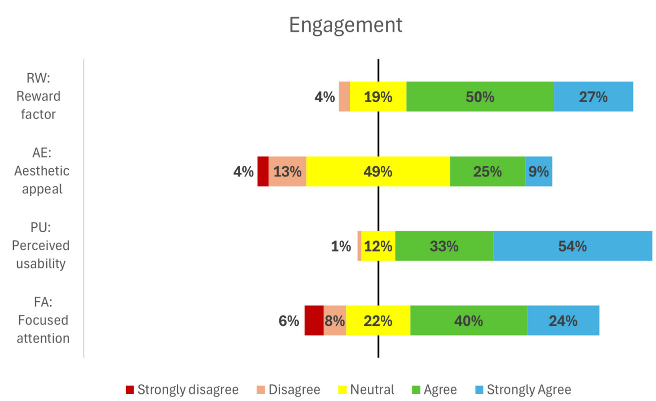

Figure 8: The four dimensions of engagement.

6.1 User Engagement

All the students were asked to give a score, on a 5-point scale, to the 12 statements that compose the UES short form [24] and are related to the four factors that, according to O'Brien et al., define the engagement dimensions: reward (sum of novelty, felt involvement, and endurability), aesthetic appeal, perceived usability and focused attention. As shown by Fig. 8, the perceived usability and the reward gained very high scores, while the aesthetic appeal obtained lower scores, although higher than the neutral threshold of 3. The overall engagement score, derived from the mean value of the statements, was 3.83, notably higher than the average score of 3.

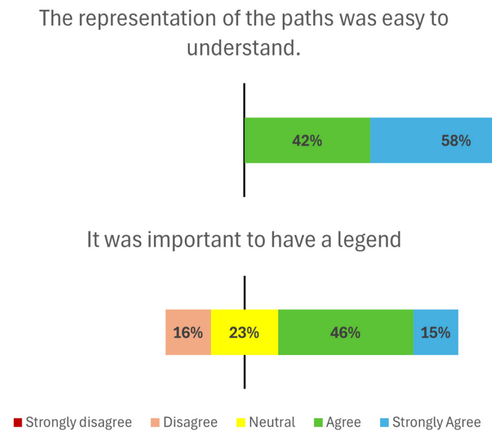

Figure 9: Representation of data along the path.

6.2 Representation of Data along the Path

In this section of the survey, the participants were asked if the data representation was easy to understand and if it was important to have a legend explaining the meaning of the different parts of the representation. Results, displayed in Fig. 9, show a very high level of appreciation for the interface; the legend was also felt important, even if a limited number of students didn't agree about its usefulness. A complementary open question was meant to capture suggestions about improving the representation. The most relevant answers included the request for a live map during the walk, darker colors for the path to increase the contrast with the light-colored map, and the display of numerical data after tapping a point on the path. The students were also asked if the information provided by the application was enough for making decisions. Most of the answers were on the positive side of the 5-point scale (means=4), and no answer was below 3 points. However, in a related open question, some students stated they would have liked additional data, including PM2.5 and PM10, and a better identification of green areas.

6.3 Impact of the Gaming Experience on Awareness and Behavior

The initial open question was meant to understand the strategies adopted during the game for lowering the CO_2 levels during the return journey. Participants declared that they considered different environmental factors (i.e., traffic, people, type of urban environment, weather conditions) as possible causes of increased CO_2 levels. Consequently, they tried to avoid areas with a high density of vehicles and people, tried to walk through green spaces, and preferred windy and open areas.

The following two questions were meant to capture the opinions about the potential of the CO_2 tracker to improve the awareness of citizens about the relation between CO_2 and different types of environment, and the role that it could have for changing their habits (i.e., changing daily routes for minimizing exposure to high level of CO_2). Fig. 10 shows that they identified the walking experience with the CO_2 tracker as a valuable method for enhancing citizens' awareness. Also, the usefulness of the current tracker to change citizens' daily habits gained high scores, even if there was some disagreement. The following questions were related to investigating if the participants were likely to change their daily behavior, select the routes more carefully, and use the CO_2 tracker during their walks. The findings (see Fig. 11) show that many participants were inclined to modify their daily routes. Still, the answers related to using the current CO_2 tracker included the entire spectrum of choices (means=3.3).

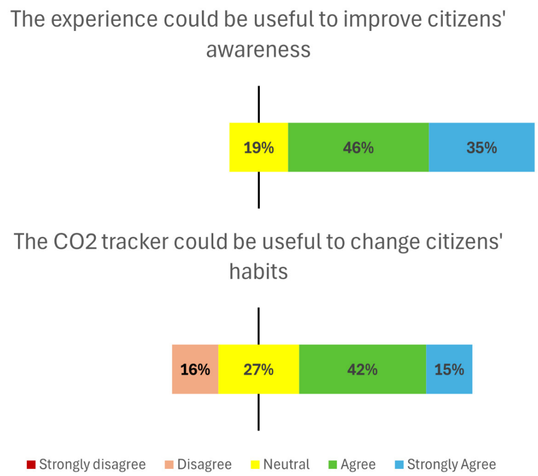

Figure 10: Impact on citizens.

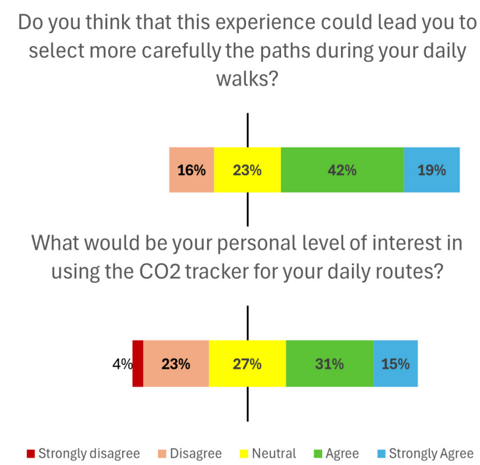

Figure 11: Personal behavior change.

The participants were also requested to provide a quantitative estimation of the extent to which they would modify their daily walking routine for obtaining lower CO_2 values, both in absolute terms (i.e., the number of meters they would increase the length of their route) and in percentage. Fig. 12 resumes the findings. Bigger circles are associated with more participants expressing the same opinion. Of particular interest is the observation of a cluster between the 20-40% and the 200-600 meters, as well as a significant number of choices (4) for the 50%/ 1000 meters pair.

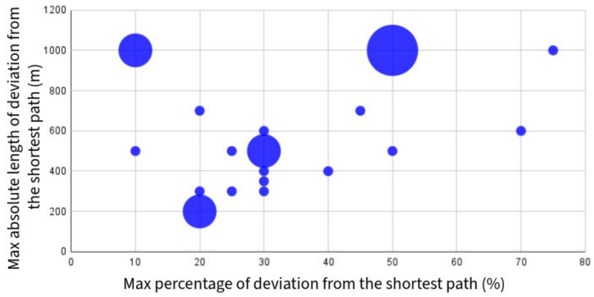

Figure 12: Maximum deviation from the shortest path.

The final three open questions focused on features that students liked more or less and suggestions for improvements. A thematic analysis [5] was conducted by the authors of this paper to extract from the answers a set of codes and identify six relevant *themes*:

(1) *Data representation*: In general, the representation was considered a point of strength of the application ("The map of the route with different colors was very clear"), but some enhancements were proposed to enhance further the comprehension ("Use darker colors on the map", "Improve representation of green areas");
(2) *Social aspects of the experience*: There were positive comments about the group collaboration and the gamification of the experience (e.g., "I enjoyed the company of the group");
(3) *Environmental context*: While some participants appreciated the outdoor experience ("It was great to do an activity outside"), others complained about the weather (e.g., "It was a cold and windy day") and the traffic in the walked routes (e.g., "there was a lot of vehicular traffic");
(4) *Interface enhancements*: Some participants requested to have a real-time overview of the relation between CO_2 and the different types of urban zones, helpful also for improving the strategy for the back route ("A live map during the game can improve the experience"); some users also asked to have a personal area for examining their routes and having additional information about the gathered data ("The experience can be improved with the possibility of signing in the application for examining personal results");
(5) *Impact on citizens*: Participants appreciated the possibility to improve the awareness about CO_2 concentration ("I can see actual data from the city where I live") and see the data in real time; some of them suggested providing more guidance ("Show alternative routes to reduce CO_2 levels", "Add more information about the impact of CO_2 in urban contexts", "Use machine learning to predict and suggest alternative routes with lower CO_2 levels");
(6) *The mobile station*: Participants appreciated experimenting with a custom-made hardware ("It was great to use a station created at the University Campus"), but some of them complained about some issues related to the prototypical nature of the device ("The station was big in size", "The reliability of the station has to be improved"); some students proposed also to add some sensors for PM2.5/PM10 which can give a more direct feedback about harmful environments.

7 Discussion and Conclusion

The participants in the workshop provided valuable feedback for answering the initial research questions.

Concerning Q1 (Can CO_2 geolocalized data be gathered and presented effectively and engagingly to citizens who are not experts in environmental issues?), most answers highlighted the engagement of the participants in taking part in the data gathering (Fig. 8) and the effectiveness of the representation (Fig. 9). The experience was appreciated (despite some issues, such as the cold weather and the traffic) because of its social aspects and the opportunity to see in real time data related to the urban environment that was part of the daily experience (see the theme *Impact on citizens*, thematic analysis in Section 6). Participants also suggested some changes to the interface to improve the representation further (see the theme *Data representation*, thematic analysis in Section 6).

Concerning Q2, (Can the gathering experience with the CO_2 tracker effectively improve citizens' awareness about the relationship between carbon dioxide levels and the environment?), the answers related to the citizens' behavior change (Fig. 10-first stacked bar) highlight that most participants supported the idea that the experience could improve the citizen's awareness. Answers related to the strategies adopted for guessing the best return path reveal that the users attempted to identify the relation between CO_2 and the different environmental factors. And, despite the various weather conditions, most groups succeeded in diminishing, at least slightly, the exposure to CO_2 during the back route. Users demonstrated interest in the issue, providing suggestions for further improving the participants' awareness (see the theme *Game enhancements*, thematic analysis in Section 6).

Concerning Q3 (Can the gathering experience with the CO_2 tracker be helpful to change the citizens' habits during their daily paths?), we should distinguish between the impact of the type of experience and the prototypical tracker implemented for the experiment. Most participants strongly agreed or agreed that the experience could be useful to improve citizens' awareness (Fig. 10-first stacked bar). Many participants also were inclined to select more carefully their daily routes (Fig. 11-first stacked bar). A large part of them declared to be available to increase by at least 20% or 200 meters their daily routes, which represents a significant result (Fig. 12). Some participants declared that they were available even for massive deviations to have health benefits. However, while participants appreciated the effort put into the design and implementation of the tracker, there were some concerns about its size and prototypical nature, which led to mixed answers about the hypothesis of bringing the prototypical station into daily routes (Fig. 11-second stacked bar).

Overall, the experiment confirmed the initial work hypotheses and, at the same time, gave helpful suggestions for the future development of the platform. One of the most relevant issues was related to the hardware. At the start of the project, no off-the-shelf device was available, and we wanted to experiment with different CO_2 sensors to select the best one. All of this led to designing a modular architecture, shown in Fig. 11, based on components that had to comply with several requirements, including flexibility, quality of sensors, low battery consumption, and connection capability. While this architecture still will be helpful for further experimentation (e.g., introducing additional sensors, as the PM2.5/P10 detectors mentioned by some participants to the workshop), a wider diffusion and inclusion in everyday activities would require putting extra effort into the miniaturization and industrialization of the device.

Concerning the interaction with the web application, some of the observations, as the suggestion of alternative paths for minimizing the CO_2 levels based on machine learning, can be useful for daily use and probably would increase the number of people interested in using the platform. At the same time, we believe these suggestions should be coupled with an interface that explains the reason for the suggestion, to maintain the initial goal of improving citizens' awareness. Regarding the improvement of the interface, an additional effort will be put in making clear the existence of functionalities that some participants asked for but were already available (i.e., the functionality that enabled users to tap a specific point on the map to reveal the actual data for that location).

While the platform already supports the possibility to filter the sessions using the acronym selected, the introduction of a personal area containing all the sessions recorded by a given user can be a valuable addition for those persons interested in having a smoother access to data collected by them and introduce additional gamification mechanisms, as leader boards or other widgets targeted to improve further citizens' engagement.

The study has some limitations, including the use of the aforementioned prototypical hardware and the fact that the evaluation was performed with master's students in computer science. While it is helpful to underline again that the students had only an average knowledge of CO_2-related issues, following experimentation should also include citizens with different skills and ages, for a more comprehensive evaluation of the citizens' interest in the platform.

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References

[1] Md. Saniul Alam, Paul Duffy, Bernard Hyde, and Aonghus McNabola. 2018. Downscaling national road transport emission to street level: A case study in Dublin, Ireland. *Journal of Cleaner Production* 183 (2018), 797–809. doi:10.1016/j.jclepro.2018.02.206

[2] Rick Bonney, Tina B. Phillips, Heidi L. Ballard, and Jody W. Enck. 2016. Can citizen science enhance public understanding of science? *Public Understanding of Science* 25, 1 (2016), 2–16. doi:10.1177/0963662515607406

[3] Gabriella Buffa. 2022. *Life Redune LIFE NAT/IT/000589.* Ca' Foscari University of Venice. Retrieved July 23, 2025 from https://liferedune.it/

[4] Anna R. L. Carter, Marianna Obrist, Christopher Dawes, Alan Dix, Jennifer Pearson, Matt Jones, Dimitrios Zampelis, and Ceylan Beşevli. 2023. Scent In-Context: Design and Development around Smell in Public and Private Spaces. In *Companion Publication of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23 Companion)*. Association for Computing Machinery, New York, NY, USA, 138–141. doi:10.1145/3563703.3591455

[5] Victoria Clarke and Virginia Braun. 2017. Thematic analysis. *The Journal of Positive Psychology* 12, 3 (2017), 297–298.

[6] Paul Denny. 2013. The effect of virtual achievements on student engagement. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 763–772. doi:10.1145/2470654.2470763

[7] Adrián Domínguez, Joseba Saenz de Navarrete, Luis de Marcos, Luis Fernández-Sanz, Carmen Pagés, and José-Javier Martínez-Herráiz. 2013. Gamifying learning experiences: Practical implications and outcomes. *Computers & Education* 63 (2013), 380–392. doi:10.1016/j.compedu.2012.12.020

[8] Earthwatch. 2025. *Earthwatch.* Retrieved July 23, 2025 from https://www.earthwatch.org

[9] Ann Forsyth and Michael Southworth. 2008. Cities Afoot—Pedestrians, Walkability and Urban Design. *Journal of Urban Design* 13, 1 (2008), 1–3. doi:10.1080/13574800701816896

[10] Kirk Goldsberry. 2005. Limitations and potentials of real-time traffic visualization for wayfinding. In *Proceedings of the 22nd ICA/ACI International Cartographic Conference* (A Coruña, Spain).

[11] Google. 2025. *Use eco-friendly routing on your Google Maps app.* Retrieved July 23, 2025 from https://support.google.com/maps/answer/11470237?hl=en

[12] Lasse Hakulinen, Tapio Auvinen, and Ari Korhonen. 2013. Empirical Study on the Effect of Achievement Badges in TRAKLA2 Online Learning Environment. In *2013 Learning and Teaching in Computing and Engineering*. 47–54. doi:10.1109/LaTiCE.2013.34

[13] David Hunter. 2020. Data walking. In *Proceedings of the 16th Participatory Design Conference 2020 - Participation (s) Otherwise-Volume 2.* 188–191.

[14] David Hunter. 2022. *Data Walking.* Retrieved July 23, 2025 from https://www.datawalking.com

[15] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *Proceedings of the 33rd annual ACM Conference on Human Factors in Computing Systems.* 3227–3236.

[16] Andy Kirk. 2019. *Data visualisation: A handbook for data driven design.* SAGE Publications Ltd. 1–328 pages.

[17] Rob Lemmens, Vyron Antoniou, Philipp Hummer, and Chryssy Potsiou. 2021. *Citizen Science in the Digital World of Apps.* Springer International Publishing, Cham, 461–474. doi:10.1007/978-3-030-58278-4_23

[18] Ria Hutabarat Lo. 2009. Walkability: what is it? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability* 2, 2 (2009), 145–166. doi:10.1080/17549170903092867

[19] Ko Ko Lwin and Yuji Murayama. 2011. Modelling of urban green space walkability: Eco-friendly walk score calculator. *Computers, Environment and Urban Systems* 35, 5 (2011), 408–420. doi:10.1016/j.compenvurbsys.2011.05.002

[20] Annapaola Marconi, Michela Ferron, Enrica Loria, and Paolo Massa. 2019. Play&Go, an Urban Game Promoting Behaviour Change for Sustainable Mobility. *Interaction Design and Architecture(s)* (04 2019), 24–45. doi:10.55612/s-5002-040-002

[21] Karolina E. Mellor and Philip Coish. 2018. The safer chemical design game. Gamification of green chemistry and safer chemical design concepts for high school and undergraduate students. *Green Chemistry Letters and Reviews* 11, 2 (2018), 103–110. doi:10.1080/17518253.2018.1434566

[22] Erik Minge, Cortney Falero, Greg Lindsey, Michael Petesch, and Tohr Vorvick. 2017. Bicycle and Pedestrian Data Collection Manual. https://hdl.handle.net/11299/188996

[23] Siobhan O'Donovan, James Gain, and Patrick Marais. 2013. A case study in the gamification of a university-level games development course. In *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference* (East London, South Africa) *(SAICSIT '13)*. Association for Computing Machinery, New York, NY, USA, 242–251. doi:10.1145/2513456.2513469

[24] Heather L. O'Brien, Paul Cairns, and Mark Hall. 2018. A practical approach to measuring user engagement with the refined user engagement scale (UES) and new UES short form. *International Journal of Human-Computer Studies* 112 (2018), 28–39. doi:10.1016/j.ijhcs.2018.01.004

[25] Fabio Pittarello and Lorenzo Brutti. 2019. A public tangible interface for engaging and informing young citizens about climate change. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays* (Palermo, Italy) *(PerDis '19)*. Association for Computing Machinery, New York, NY, USA, 6 pages. doi:10.1145/3321335.3324938

[26] Fabio Pittarello and Manuel Semenzato. 2024. Towards a Data Physicalization Toolkit for Non-Sighted Users. In *2024 IEEE 21st Consumer Communications & Networking Conference (CCNC)*. 1–6. doi:10.1109/CCNC51664.2024.10454861

[27] Raspberry Pi Foundation. 2015. *Raspberry Pi Zero.* Retrieved July 23, 2025 from https://www.raspberrypi.com/products/raspberry-pi-zero/

[28] USGS. 2025. *North American Breeding Bird Survey.* Retrieved July 23, 2025 from https://www.usgs.gov/centers/eesc/science/north-american-breeding-bird-survey

[29] Christine A. Ward-Paige, Camilo Mora, Heike K. Lotze, Christy Pattengill-Semmens, Loren McClenachan, Ery Arias-Castro, and Ransom A. Myers. 2010. Large-Scale Absence of Sharks on Reefs in the Greater-Caribbean: A Footprint of Human Pressures. *PLOS ONE* 5 (08 2010), 1–10. doi:10.1371/journal.pone.0011968

[30] Darren Wilson, Cynthia Calongne, and Brook Henderson. 2015. Gamification Challenges and a Case Study in Online Learning. *Journal of Online Learning Research and Practice* 4, 2 (sep 1 2015).

[31] David Worrall. 2019. *Sonification Design: From Data to Intelligible Soundfields.* Springer. doi:10.1007/978-3-030-01497-1