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Teaching urban sensing skills - experiences from a summer school

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Abstract. Sustainability has become an important topic in higher education, with low-cost and open-source sensing platforms for urban monitoring emerging as tools to engage students in formal and informal learning experiences. In this context, we present our experience with the de-sign and implementation of a five-day summer school aimed at teaching urban sensing techniques. The summer school engaged graduate students from diverse disciplines, including engineering, architecture, environmental science, and social science. Participants gained hands-on experience with designing and executing urban sensing experiments to investigate research questions developed by the participants, using an open-source urban sensing platform provided to the students. They also developed scientific literacy skills such as problem elaboration, data visualization, and communication with non-experts. The impact of the summer school was evaluated via interviews, digital surveys, and author observations, unveiling three key themes: effective teaching practices for urban map-ping tools, factors inhibiting learning, and factors promoting scientific literacy. We discuss how our findings can be applied to the development of similar learning initiatives.

Keywords: Urban sensing, Internet of Things, Environmental science, Learning, Collaboration, Workshop

1 Introduction

Sustainability has become an important topic in higher education [32, 17]. In this context, low-cost and open-source sensors for urban monitoring (e.g. [9, 10]) are emerging as tools to engage students in formal and informal learning experiences. Several citizen science projects [18, 19] have shown how low-cost sensors have been used in educational settings. Yet, while participants gain knowledge about specific contexts and cases, they often lack an understanding of the underlying scientific processes [3, 4].

Educating students in higher education about urban sensing techniques is essential, especially since policymakers often rely on insights from citizen science projects [3]. Urban sensing refers to the collection and analysis of data related to urban environments such as noise, temperature, or air pollution. Ensuring the validity of the data collected is crucial [3], given the complexity of the urban science field's multidisciplinary nature, spanning engineering, social science, and statistics. As graduate students begin their careers in areas such as data science or urban planning, it is important for them not only to understand the processes involved in urban sensing studies but also to have firsthand experiences with the steps involved and related challenges in designing and implementing such studies, e.g. via data collection experiments.

For this paper, a 5-day in-person project-based summer school for graduate students in higher education is being analyzed. The strength of the summer school is to teach graduate students working in different fields about the processes behind urban studies, with the goal of teaching urban sensing skills. The summer school was organized by three of the authors of this paper.

This research aims to understand how the different in-person learning activities implemented during the summer school impacted the graduate students' engagement and skills, and if they had relevance to their careers and current work.

To this goal, we first present project-based learning (PBL) and previous work on teaching urban sensing skills. Then we describe the summer school learning activities describing lectures, fabrication, project development, data collection and analysis, and presentation of results. Following we report results from the evaluation of the summer school performed via surveys, interviews, and observations before we discuss limitations and lessons learned. We aim to shed light on how in-person workshop-based educational activities can be used as tool to teach urban sensing skills.

2 Related Work

In this section, we review research on project-based learning in higher education and previous work on urban sensing. We examine the potential of using diverse learning activities to enhance graduate students' understanding of urban sensing methods.

2.1 Project-Based Learning in Education

Project-based learning (PBL) methodologies represent an approach to education that improves critical thinking skills and emphasizes student-centered, interactive, and experiential learning over traditional teacher-centric lectures [8]. A comprehensive review of over five hundred projects in computer science education utilizing project-based learning techniques [1] highlights their high value for students. Notably, projects initiated by students themselves or based on their suggestions yield particularly favorable outcomes, likely due to heightened self-motivation [1, 20].

PBL is a variant of self-organized learning, which focuses on experiential and interdisciplinary projects enabling students to contribute their skills and interests by doing concrete tasks. Successful implementation of these activities requires students to possess a certain level of knowledge to organize themselves, guided by the teacher throughout the project. Key teaching principles in PBL include situation-relatedness, action-relatedness, and science-relatedness [1].

Previous research acknowledges students' awareness of the increased workload associated with PBL and the change from passive to active learning approaches [31]. PBL success depends on various factors, including personal characteristics [24]. Nevertheless, PBL has consistently enhanced interdisciplinary knowledge acquisition across diverse educational contexts [21, 33, 23].

2.2 Teaching urban sensing skills

Teaching urban sensing skills requires a multidisciplinary approach including Internet of Things (IoT), data science, and urban studies, challenging students from different fields and backgrounds to work together. Combining all of these learning activities might lead to several challenges in the respective fields.

Previous research on teaching IoT has revealed different methods for introducing IoT into computer science curricula [13]. This research underscores the interdisciplinary nature of introducing IoT, with not only technical aspects but also social considerations such as ethics and privacy. One approach highlighted by this research is to adjust college courses to align with specific use cases. This underlines the importance of presenting IoT at the intersection of different disciplines. In addition, the study emphasizes the practical difficulties in combining hardware and software and the necessity for instructors to have well-prepared teachers' resources and tools.

Previous work on "datathons" - where students compete by working on different datasets over a weekend, highlights the importance of having participants choose their working groups and have a clear and realistic goal from the beginning of the learning activity to be able to get results within the limited time [12]. It also suggests inviting participants to mix up with different skills over the different teams so that others can learn from them. One problem that emerged was the understanding of data and data availability. For them to make the best use of the data, the data needed to be "well structured, clean, and anonymized".

The literature reveals that existing approaches typically focus on specific aspects, such as educating IoT [13], establishing an environmental science project [14], or data analysis [12], each accompanied by its own findings and challenges. To our knowledge, no educational activities have been made to manage all stages of the process, from problem definition and creation of an urban sensing platform to hands-on data gathe

3 Structure of the summer school

The summer school was held in 2023 in a large European city and centered around the theme of “decarbonizing cities and the social cost of climate change.”. The school lasted for five days. Its primary objective was to teach skills that are relevant to performing urban sensing studies activities such as lectures, team-based project development, prototyping, data collection and analysis, and public presentation of findings.

The participants in the summer school came from academic disciplines. They were selected through an application process, which was advertised on local universities’ campuses. The applicants were evaluated by a committee based on their background and motivation to attend the school. The committee aimed to maximize diversity in background and experience among participants, making sure that all disciplines (architecture/design, mechanical engineering, environmental science, coding/computer science, and urban planning) had an even representation. Approximately half of the applicants intended to commence master’s stud-ies in the same city, focusing on sustainable development and urban innovation [37].

On the first summer school day, to form project teams, participants were allocated a color identifier representing their background. Then they were asked to form diverse groups of 5 participants possessing a wide range of color designations.

The project given to participants during the summer school is rooted in an open-source mobile urban sensing platform Flatburn designed by three of the school organizers. Each group of participants was asked to create a project where urban data from the urban sensing platform was to be used to either answer a research question or to design a product or service. Two example applications developed by the participants were to test air pollution on different commutes to help people choose the least polluted way of transport and to monitor the air pollution on bike lanes close to schools to see to what extent cycling is healthy for school children. An overview of the platform is shown in Figure 1. The summer school took place over five days and facilitated senior researchers and professors in the fields of urban studies, computer science, and environmental science.

Fig. 1. Parts used for fabrication of the urban sensing platform (left), teams during the prototyping phase (middle), teams during data collection (right)

This section provides an overview of the summer school's schedule and activities.

3.1 Summer School Overview

The learning activities of the summer school can be divided into six categories, each with specific learning goals as reported in Table 1. The schedule allowed participants to engage in a variety of activities, including lectures, hands-on fabrication, ideation, urban data collection, urban data analysis, and presentation preparation. Each day had a specific focus and built upon the knowledge and skills acquired in the previous days.

Table 1. Overview of Summer School Activity Categories and Learning Goals

Day nr.	Category	Learning Goals
1, 3	Lectures, keynotes, site visit, and panel discussion	Understand the context and related work in the field of urban sensing.
2	Fabrication / prototyping	Understand the principles behind the technical components needed to fabricate an urban sensing platform.
3	Project development	Foster collaborative skills by working in multidisciplinary teams. Develop the ability to identify and articulate specific urban challenges that can be addressed through sensing technologies.
3, 4	Data Collection	Develop skills in planning and executing an urban data collection experiment within a specified context (defined in the project development phase).
4, 5	Data Analysis	Understand the importance of urban data validation, calibration, and quality assurance for reliable results. Extracting high-level insights starting from raw, noisy sensor data.
5	Presentation of results	Learn effective communication techniques to enhance the presentation of findings.

3.2 Learning activities

The workshop activities were designed to provide participants with a holistic understanding of urban sensing and foster their ability to work collaboratively on an urban study project.
The activities included:

Lectures, Keynotes, Site visit, and Panel Discussions. The summer school started with lectures and keynote presentations, introducing participants to the fundamentals of environmental science. Topics such as decarbonization and the societal cost of air quality were discussed, offering insights into urban environmental variations. Researchers from various fields led these sessions, ensuring an interactive and engaging learning experience. A site visit to a research facility illustrated real-world applications of urban monitoring, further enriching the learning process and demonstrating ongoing research within the field.

On day 3, subsequent lectures offered both insights into the importance of scientific storytelling, and a more detailed explanation of the urban sensing platform's technical aspects. The participants were able to attend either of these two classes. These sessions aimed to increase participants' understanding of data collection and narrative skills in scientific research.

Fabrication / prototyping Fabrication of the urban sensing platform happened on day 2. Participants were led through the fabrication with explanations of each of its components. Guides on how to fabricate the urban sensing platform, together with source code were made available to the participants. Previous studies emphasize the benefits of Open-Source Hardware (OSHW) that has be-come increasingly applied in a variety of educational contexts; getting familiar with new technologies, e.g. for examining concepts in science or engineering; and promoting active participation in product design [25–27]. Such hands-on experiences stimulate creativity and boost student engagement [21].

Project Development Development of the project scope was an iterative process happening on day 3, depending on each team and how fast they managed to find a project they wanted to work on. Participants engaged in the ideation and development of a project using the urban sensing platform. Urban data collected by the platform included air pollution (PM1, PM2.5, and PM10), noise levels, temperature, humidity, and nitrogen dioxide (NO2). The data was tagged with a timestamp and GPS coordinates. Using the data, the groups were challenged to build a project where the collected urban data could help them answer a hypothesis for the following 2 days (before the summer school ended). Using provided tools and a roadmap on how to develop different use cases to form their projects, groups conceptualized potential applications to create project requirements and foster a better understanding of the project's objectives and applications [28].

Data Collection Urban data collection was performed over day 3 and day 4, depending on the project, where groups gathered urban data in diverse urban settings related to each unique project. Existing research underscores the positive correlation between student engagement and the inclusion of geo-spatial technologies in their studies [29]. Participants used the platform to collect urban data, creating excitement with their work and enhancing their learning experiences.

Data Analysis For the urban data analysis performed on days 4 and 5, participants used a computational notebook based on the Python programming language. The notebook is available as part of the open-source urban sensing platform utilized during the school. The notebook included a set of code snippets that participants can combine and customize to calibrate and validate the data and perform simple urban analysis tasks, including identifying trends an hotspots and plotting graphs. The notebook provided a hands-on approach to urban data analysis, encouraging participants to modify code and experiment to get familiar with the dataset they have collected during the previous phase of the summer school [2]. Rather than providing explicit facts in the notebook, techniques derived from project-based learning were employed to promote the learning of concepts and principles used to evaluate data from complex real-world problems [5].

Presentations of project results The summer school ended on day five with presentations of the projects and their findings, where each group was challenged to present their research in a concise format in front of an audience. By using the format of *Pecha Kucha* presentations, groups communicated their results. This style, translating to "chitchat" in Japanese, involves presentations with 20 slides, each displayed for 20 seconds. Such a method has been shown to improve the focus and effectiveness of presentations, rated higher than traditional PowerPoint formats [30].

4 Summer School Evaluation

This section presents the analysis of the summer school outcomes, drawing from various research data sources, including the writer's observations as a participant in the school, interviews with participants, and an online survey. The summer school involved thirty participants (nineteen female, eleven male), aged 22-30 years old, representing diverse academic disciplines like architecture/design, mechanical engineering, environmental science, coding/computer science, and urban planning.

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The survey was sent two months after the summer school took place and received fifteen responses (50% of participants). The survey assessed the out-comes of the school in three areas: engagement, skill development, and career impact. A 7-point Likert scale was adopted, and the data was analyzed using descriptive statistical methods. This method provided a standardized analysis, complementing the subjective nature of direct observations [6] and interviews with participants. Additionally, semi-structured interviews with five of the participants were conducted to further question how participants applied their new skills in current studies and professional work [7]. Interviews were transcribed and analyzed using thematic analysis to identify, analyze, and report patterns in the data [11]. The thematic analysis was done by transcribing the interviews to ”codes” (statements or observations related to the aim of the research). This process was done three times to explore different options and identify the right path to follow [33]. Then the codes were grouped into different themes related to the aim of the research. To generate themes from the codes, all codes were clustered together in a spreadsheet to visualize the most frequently highlighted feedback from the interviews. Following this, a short brainstorming session was conducted to extract themes from these clusters and define them.

By using the 7-point Likert scale from 1 (Strongly disagree) to 7 (Strongly agree), the surveys show a high mean value for all three different metrics scores illustrated in Table 2, where the values are between 6 (agree) to 5 (Somewhat agree). The term “engagement” refers to the degree to which individuals are mentally and emotionally invested in the activities. This encompasses their active participation, enthusiasm, and genuine interest, which contribute to a more meaningful interaction with the content and other participants. The “skills” are how the participants felt their skills improved during the different activities, e.g. *«I developed valuable skills in how to work with environmental data collection from the workshop.”*, while the “impact” shows how much the participants now believe the skills developed still have an impact on their current work, e.g. *“The data analysis methods and skills developed in the workshop, continue to be valuable in my ongoing work.”*. The majority of participants responded positively, with only a few providing lower scores. This shows that the summer school was generally well-received.

Table 2. Summary of Mean Scores, Min, and Max for different metrics

Metric	Mean	Min	Max
Engagement	5.64	1	7
Skills	5.42	3	7
Impact	4.79	2	7

The thematic analysis identified three primary themes: best practices in teaching to graduate students urban sensing skills, factors inhibiting the learning of urban sensing skills, and factors promoting scientific literacy skills.

Best Practices in Teaching Graduate Students Urban Sensing Skills. The survey answers show that participants found the summer school enjoyable and expressed a willingness to recommend it to others. The hands-on experience of working with physical Internet of Things (IoT) devices, such as the urban platform, was well received, as a participant commented, a *"pleasant surprise"*. Participants noted that fabricating the platform helped them *"demystify"* the *"black box"* of how urban sensing tools work. Another participant remarked, *"What inspired me the most is the part that I did not see - how the platform and techniques of measuring can just be very diverse..."* This active hands-on engagement with the platform proved to be an enlightening experience for many.

Additionally, the showcase of their project, inspired participants, encouraging them to learn from each other's project's iterations and related challenges. As an example, one participant stated in the interviews, that she intended to *"...use the platform as an example and continue to iterate on the work that has been done. I use the experiences"*.

Factors Inhibiting the Learning of Urban Sensing Skills. Despite the generally positive reception of the summer school, certain elements hindered the learning process. Both the survey and interviews revealed issues related to misaligned perceptions and expectations regarding the overall objectives, as the answers were distributed. Some participants expected a more technical focus and found that the original summer school theme, "Climate change and social costs" did not align with the summer school's actual outcome. As one participant mentioned, some lectures were not *"mind-blowing"* and were easy to forget. Another noted that the lectures could be *"somewhat scattered and general with no direct relevance to the main theme"*, indicating a perceived mismatch between theory and practice.

Challenges related to urban data collection and analysis also emerged as obstacles. Technical issues during urban data collection left some participants confused and frustrated, as they had to rely on quick fixes provided by facilitators during the data collection and analysis. Different expectations regarding the depth of lectures from the researchers were also mentioned, with participants expecting more in-depth content.

Several interviewees (80%) reported a lack of tangible results, and this was observed during the summer school as well. Clearer, tangible goals and expectations at the beginning of the summer school could help realistic goals for the participants. Time limitations were another challenge, as participants suggested that additional preparation time and resources given before the summer school, and more days to do the project could improve the learning process.

Factors Promoting Scientific Literacy Skills. Different factors were identified as promoting scientific literacy skills as an outcome after the summer school among participants. The experience of going from an idea to collecting urban data was highlighted as a valuable learning process. Participants reported gaining the knowledge and skills needed to implement scientific processes in their independent projects, emphasizing the practical exercises; *"...now I know I can use this myself - collect the data I need to perform the analysis myself"*.

Diverse group work and collaboration with participants from different aca-demic backgrounds and disciplines were significant contributors to the success of the summer school. Participants engaged in fruitful discussions and drew inspiration from their interactions. Soft skills, such as effective communication and teamwork, were strengthened through group work and presentations. The inter-action with people from diverse backgrounds was seen as a positive contributor to the outcomes.

5 Lessons learned

In this section, we discuss the outcomes of summer school, emphasizing its impact on introducing graduate students to skills that are relevant for urban sensing. We address lessons learned and challenges encountered during the different activities, discussing the areas that require attention and improvement. We hope that our analysis will inspire the design of similar learning activities supporting the work of both practitioners and researchers.

Importance of Expectations and Tangible Results. One key observation from the summer school is the significance of tangible results and aligned expectations as factors that can either facilitate or inhibit learning. In this context, "tangible results" refer to the outcome of the project analysis of the urban data. Four out of five interviews mentioned the lack of good results was disappointing. They reported that the problem development activity was done in a rush, leading to unclear goals and limited time to change the direction of the project. While allowing participants to choose their projects can boost motivation and results [1, 20], it can also lead to unrealistic goals. Also, the hardware problems met during data collection led to the activity taking more time than anticipated, which they did not have. When doing an intensive 5-day summer school involving all the diverse learning activities, there is limited time to fail and troubleshoot. Research on important factors for intensive "datathons" also shows the value of having all resources ready and tested to limit time for troubleshooting different problems [12].

Based on these experiences, we have two suggestions for improvements for future summer schools. Troubleshooting hardware issues is time-consuming, and you might sacrifice time from other learning activities. Making sure to have well-prepared resources and trying to minimize the number of challenges encountered can help to effectively teach participants about urban sensing technologies [13]. Another solution could be to limit the scope of projects that participants can choose from, and guide them to decide on a realistic goal, as stated by [12] as an important factor, within the time limitations. This approach could assist them in aligning their expectations, helping them to feel a sense of achievement and satisfaction with the result.

Participants had high expectations for the summer school and technology provided, partly due to its association with the organizers being researchers of a technical university. While many considered it a good introductory course for IoT sensing platforms and urban data collection, they suggested some improvements. Recommendations included refining the introductory part, incorporating more in-depth lectures on sensors, and providing an in-depth introduction to urban data collection processes. Despite these challenges, participants felt that they developed valuable skills related to urban data collection, but for future summer schools, these suggestions could also be included to increase their knowledge acquisition before the hands-on learning activities.

Summer School Demographics. Research indicates that the gender distribution in events similar to our summer school, such as hackathons, typically features an average female participation rate of 23% [16]. However, in our case, with a 63% female attendance rate, the summer school deviates from the standard demographic trends observed. While the concept of a hackathon varies, these events are generally characterized by inviting participants to form small teams and engage in intensive collaborative technology development, usually over a few days [34]. Hackathons can often target computer science students and tend to have less diverse participation compared to the demographics we needed in our summer school. However, only 45% of the participants with technology or environmental science backgrounds were male.

Understanding how this summer school managed to target a high number of women requires a more in-depth analysis and looking beyond participation numbers to their experience [34], which is not the aim of this research. However, naming the summer school a "summer school" could have improved the communication about the event to feel more welcoming "to all" [36], avoiding the name "hackathon". Critics in the literature argue that "hackathons" may reinforce the stereotype of self-assured tech specialists addressing issues for others, often by isolating themselves in a room for a weekend of coding [34]. While this is not the norm for hackatons, it is possible to engage with a diverse group of users [35].

Scientific Literacy Skills. Although participants did not explicitly state that they improved their "scientific literacy" skills, they highlighted the eye-opening experience of working on a complete research project, from idea to analyzed findings. A lecture on the development of the original platform, including lessons learned and challenges faced during development, was particularly inspiring for participants. Learning from real-world mistakes and challenges can be highly beneficial, as it prepares teams to adapt to rapid changes and fosters the incorporation of new ideas. While it cannot be clearly stated that participants acquired scientific literacy skills, insights from interviews suggest that they felt capable of applying the tools learned in their research. Participants recognized the learning activities' role in enhancing their understanding of the scientific processes involved in urban research.

Limitations. However, there are some gaps and challenges in the analysis of the summer school. The selection of participants for interviews may have introduced bias, as 80% of them shared the same master's program and background in architecture. This bias might limit the generalizability of the analysis to all graduate students in higher education. Nevertheless, extra emphasis and inclusion of participants from different backgrounds provide valuable perspectives for the analysis.

The duration allocated to each learning activity could have influenced the learning outcomes. The summer school adopted a highly intensive format to push all activities over 5 days. However, feedback from the interviews suggests that this time frame might have been too brief for the amount of new information introduced. In terms of participants both wanting a more in-depth lecture on specific technical topics and the need to implement fast solutions in the data analysis activity, having more days to dive into the field of environmental science could improve the learning outcomes. The format of the summer school with related learning activities could be possible to test over an extended period to measure how that affects the learning outcomes compared to this intensive summer school.

The survey responses also indicated a potential lack of diversity in participants' backgrounds, as evidenced by the limited variation in responses to the statement, "The knowledge acquired during the fabrication process remains actively applied in my current work." This suggests that the impact as a whole may have been influenced by participants' prior knowledge and experiences that might have been in some cases very similar.

Additionally, the interviewees' personal experience with the summer school and the relationships with the participants getting interviewed might have affected their responses. While survey responses appeared slightly more positive, interviewees may have felt more comfortable providing straightforward feedback during interviews. To ensure objectivity in future research, an independent role could be established.

Finally, the computational notebook may have had a more significant impact on participants' urban data analysis experience than anticipated. Many participants required assistance to understand the notebook, leading to quick fixes by facilitators. Further development and thorough testing of the notebook and raw urban data collected by the platform before the summer school could have alleviated these issues, ensuring that participants could fully utilize the provided tools for urban data analysis.

In conclusion, while the summer school introduced graduate students to urban data mapping, addressing challenges related to expectations, tangible results, and participant diversity is recommended as future improvements. The different learning activities' role in enhancing participants' understanding of the scientific process behind urban research is promising, but further refinement is necessary to maximize its educational impact. Still, it is essential to acknowledge some limitations in the project and methodology employed. While the learning activities designed might be suitable for its intended purpose of teaching graduate students in higher education, there are questions about how the design can be generalizable and useful for other domains and user groups, and a different time frame. The study involved a relatively small group of 30 participants, all of whom were in higher education, potentially leading to variations in expectations and prior knowledge compared to different user groups. Proposed improvements, such as refining prototypes, improving urban data analysis tools, and providing in-depth lectures, are derived from participants' experiences. Therefore, further research should explore the adaptability of the summer school structure and content across diverse research fields and target audiences. This would contribute to a more robust understanding of the educational and scientific impact and, its potential for broader applicability.

6 Conclusion and Future Work

In summary, this 5-day in-person summer school demonstrated an effective structure for introducing graduate students to urban sensing skills. However, facilitators should tailor the content with more detailed lectures based on the specific needs and backgrounds of the participants. Managing expectations and ensuring tangible outcomes emerged as primary challenges, with participants holding di-verse expectations and expressing concerns about the perceived lack of tangible results, which could impact their motivation.

Future work should focus on refining urban data collection and analysis activities to mitigate participant confusion and potentially produce more tangible results, thereby improving the overall learning outcomes. The collaborative nature of the variety of learning activities across multiple disciplines is evident, and participants reported acquiring valuable skills related to urban data handling.

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