Towards Context-Aware Classrooms: Lessons Learnt from the ACTUA Project

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Abstract. Context-aware classrooms augment traditional classrooms with unprecedented sensing and communication capabilities to monitor and analyse large amounts of contextual data. Enriching classrooms with these data opens up new opportunities to enhance the learning experience in education centres. However, implementing and deploying context-aware classrooms is not straightforward. This article describes the challenges addressed by the ACTUA project, which aims to advance the development of context-aware classrooms in primary schools.

Keywords: Context-Aware Classrooms · Ubiquitous Computing · Internet of Things · Education · Schools

1 Introduction

Technological advances are adopted to transform our cities [1], governments [2], and healthcare infrastructures [3] (to name a few) into their smart and cognitive counterparts. Schools, and classrooms in particular, are essential in today's society. These environments must be adequately set up to promote the teaching and learning processes for successful knowledge acquisition. Environmental comfort is critical to increasing productivity in workplaces and educational centres [4]. To this end, ubiquitous technologies, IoT devices and high-speed data networks enable real-time monitoring of environmental parameters at low cost. Unfortunately, this kind of monitoring is uncommon in school classrooms, despite their adverse conditions [5]. Equipping classrooms with sensing, computing and communication capabilities opens the door to context-aware classrooms, a next-generation model capable of processing vast amounts of data to adjust their behaviour (*e.g.,* devices, systems) accordingly. Building context-aware environments is not trivial. While many context-aware approximations are theoretical, deploying them in real-life scenarios is complex.

In this article, we present the main experiences, challenges, and barriers that we have faced while implementing and deploying a first approximation of context-aware classrooms within the scope of the ACTUA project. Our solution runs in a hundred classrooms in Catalonia (Spain). The rest of the article is organised as follows: Sect. 2 contextualises the goals of the ACTUA project, Sect. 3 describes

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the main challenges that we have experienced during the implementation and deployment of these context-aware classrooms, Sect. 4 elaborates on the opportunities highlighted by the teaching staff, and Sect. 5 closes the article with some concluding remarks and future research lines.

2 The ACTUA Project

The public health emergency triggered by the COVID-19 pandemic has highlighted the need for environmental sensing tools to fight airborne transmission of respiratory diseases [6]. Classrooms have many risk factors that can increase the likelihood of transmission: enclosed spaces that are typically poorly ventilated and where high levels of aerosol formation occur over extended periods of time. To make classrooms safer and more robust environments, the ACTUA project [7] aims to understand the relationship between health effects on the school population and classroom environment variables and characteristics [8]. Primary schools are the main target of this project.

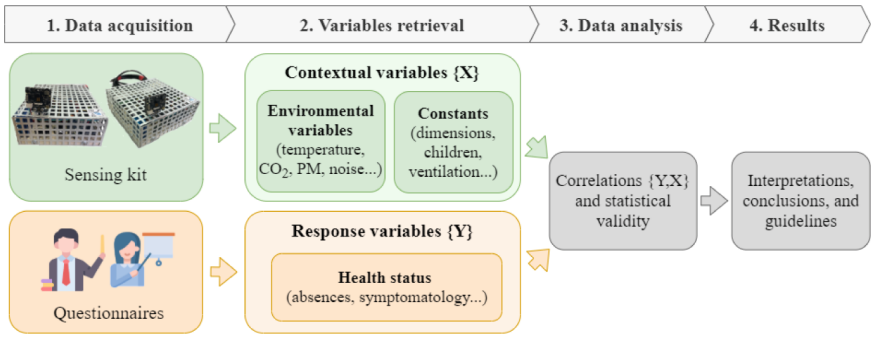

Fig. 1. Overview of the ACTUA project from a data perspective.

In keeping with the smart healthcare paradigm [9], the context of the classrooms is monitored automatically using low-cost sensing kits [10]. In particular, several classroom context variables are periodically collected, namely air temperature, relative humidity, barometric pressure, CO_2 concentration, particulate matter, light, UV radiation, ventilation, noise, and people's movement. Moreover, since classrooms can vary greatly (especially between schools), other constants must also be taken into account for a proper analysis, such as the size, floor and orientation of each classroom, the number and age of children in that classroom, and the number and dimensions of doors and windows per classroom, among others (see Fig. 1). Teachers fill out weekly questionnaires to measure the health status of the classroom's population. There, information about how many students were absent (disaggregated by reason—illness, non-medical, unknown—and temporality) or how many students had symptoms of respiratory disease is asked. During the 2022/23 academic course, our solution has been steadily installed in a hundred classrooms throughout Catalonia.

3 Challenges

Developing context-aware classrooms raises challenges, not only technical but societal and regulatory. Next, we highlight the main challenges addressed.

3.1 Technical

Sensing capabilities are the cornerstones of a contextual classroom. In this sense, nanotechnology, pervasive electronics, ubiquitous computing, and IoT devices are vital enablers. Sensing devices with self-awareness, self-reconfiguration, and self-healing are desirable to achieve absolute resiliency. This would enable devices to prevent, detect and respond autonomously to any event or failure that could affect their operation. However, these features are constrained by sensing devices' limited computational capabilities, memory and power limitations.

Our sensing kit comprises a Raspberry Pi, a single-board computer acting as a controller node, connected to several sensors that periodically collect contextual variables. To keep costs down, low-cost sensors are used, such as the SCD30 sensor to measure air temperature, relative humidity and CO_2 concentration, and the PMS5003 sensor to measure particulate matter [10]. These sensors are suitable for integration into context-aware environments because of their simplicity, efficiency, cost, and ease of programming [11]. However, their accuracy is inferior to that of professional metres, which are usually very expensive, require calibration and allow offline measurements [8].

Beyond sensing capabilities, communication and information sharing are additional required capacities. In particular, these are fundamental to properly coordinating and managing the whole infrastructure. In our solution, sensing kits have different communication channels. For instance, the sensing kits use the *aliveness channel* to inform external entities that they are up and running. This channel detects malfunctioning devices when they do not send signals periodically. Besides, there is a *data channel* wherein devices can transmit the collected data to external parties if needed. Also, sensing kits can react to messages received from external entities through the *command-and-control (C&C) channel*. The C&C functionality permits controlling devices remotely with predefined commands, such as modifying configuration parameters or executing specific operations. Hence, this channel allows devices to coordinate among themselves upon failures or external events. All these communication channels run over the HTTPS protocol to keep communications secure.

3.2 Societal

Augmenting classrooms with technology must go hand in hand with the social acceptance of the school population. The functionalities of context-aware classrooms must be transparent to students and teachers and must not interfere with teaching. For this reason, devices should be small, discreet, minimally intrusive, plug-and-play and well-integrated into classrooms. In addition, any interfaces

that require user interaction should be intuitive and as simple as possible to enhance the user experience.

However, these technological advances might cause scepticism among teachers because they have a negative perception of surveillance, resembling "Big Brother" scenarios. Concerns could magnify when augmenting classrooms with microphones or cameras for measuring ambient noise, voice recognition, locating people, or tracking people's movements. Informing and educating teachers, students and families about what context-aware classrooms can and cannot do is paramount. Societal readiness will be critical to the success of this paradigm.

3.3 Regulatory and Ethical

The ubiquity nature of context-aware classrooms makes user awareness complex. Current data protection regulations, such as the EU General Data Protection Regulation, make consent and awareness mandatory before data processing. As data can be collected opportunistically in context-aware classrooms, balancing meeting legal obligations and developing innovative, ubiquitous services is challenging. In this line, but primarily because most of the classroom population is underage, all systems must be built upon privacy-by-design principles, encompassing an ethical dimension in technological design. For this reason, transiting from regular classrooms to context-sensitive classrooms will not happen overnight.

Ethical committees analysed the ACTUA solution before its deployment in real school classrooms. In particular, we highlight the three most sensitive aspects that we had to address to be legally and ethically compliant: (i) measuring the classroom's noise using a microphone in the sensing kit, (ii) measuring people's movements using a camera in the sensing kit, and (iii) the collection of health data. Regarding noise measurements, the sensing kit computes the average sound level of the classroom (in decibels) without using voice analysis or speech recognition. The main drawback is that this value is susceptible to external noises (*e.g.,* vehicles, pedestrians). Regarding people's movement, we designed a numerical algorithm that compares people's places frame-by-frame using the YOLOv3's object recognition algorithm [12]. Avoiding taking images and recording videos relaxes privacy threats.

Regarding health data, the collection of medical records from students and teachers is bureaucratically complex. As an alternative approach, we have designed questionnaires that quantify the general health of the classroom population rather than asking for individual health data. These questionnaires are answered every week by the teachers in the classroom.

3.4 Deployment

Classrooms vary widely in terms of dimensions, equipment and furniture distribution, electrical installation and Internet availability, among other things. These differences are accentuated among schools, so there is no standard way to deploy our solution. For instance, our sensing kits are located in different places:

some are on top of tall cabinets, on shelves at medium height, or the teacher's table, and either closer to the windows, the door or at the back of the classroom. This decision depends on the availability of wall jacks, the Internet connectivity through RJ45 sockets (if WiFi is not possible), and the teaching staff's approval. Hence, installations had to adapt to each classroom's configuration.

From a technical perspective, network configurations vary among schools. We observed that schools with specific IT departments generally place more emphasis on network security (*e.g.,* strict-policy firewalls, MAC address filtering, ports disabled such as FTP. . .). Besides, when connecting devices to the school's WiFi, it is worth noting that any change in its configuration (*e.g.,* changes in the SSID or password) will require re-configuring the devices. These aspects must be considered to enhance the system's maintainability.

4 The Perspective of Teachers

Our solution has been running in 101 classrooms distributed across 38 primary schools during the 2022/23 school year. A questionnaire was distributed to the teachers and principals at the end of the course to assess our solution's acceptance and evaluate the possibilities for contextualised classrooms.

From the teachers' perspective, the technological components installed in their classrooms are not a problem. 84% report that the sensing kit has not caused any distraction to students, and 86% agree that it has not interfered with their teaching tasks. Regarding health questionnaires, around 85% of the teachers were committed and highlighted that filling them out was not an issue. Reporting this information once a week seems acceptable since 77% of the teachers could not report it more assiduously, *e.g.,* every day. Also, most teachers (57%) think that the family members of the students should report this health information. Overall, the teachers' opinion on our solution is very satisfactory (59%) and satisfactory (34%).

According to principals, 76% think that learning processes could be improved by exploiting and monitoring contextual data, and 66% will report these data to improve workplace conditions to the extent possible. Indeed, almost all principals (91%) agree on integrating monitoring systems, such as the ACTUA solution, in future schools. Regarding virus transmission, 94% of the principals believe classrooms play a crucial role in spreading disease. On this basis, 85% of them would find useful our solution to monitor and predict infections in the case of a new pandemic. All things considered, the overall perception of our solution among principals is very satisfactory (61%) and satisfactory (33%).

5 Conclusions

The addition of technology will enable context-aware classrooms, a groundbreaking paradigm with many new educational opportunities. However, this transformation will be gradual due to the many challenges that must be addressed.

Thanks to the experience gained during the ACTUA project, we have experienced first-hand the technical, societal, regulatory, ethical and deployment barriers to making context-aware classrooms a reality. Although our solution is only a first approximation, the opportunities to improve quality of life and teaching processes for more successful learning are enormous. With the consolidation of context-aware classrooms, networks of classrooms and schools could emerge to communicate with each other and share their experiences and knowledge. This would lead to a new paradigm of distributed, contextualised learning institutions.

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References

1. Machin J et al (2021) Privacy and security in cognitive cities: a systematic review. Appl Sci 11(10):4471
2. Jimenez CE et al (2016) Smart government: opportunities and challenges in smart cities development. In: I. Management Association (ed), Civil and environmental engineering: concepts, methodologies, tools, and applications, pp 1454–1472
3. Batista E et al (2023) Smart health in the 6G era: bringing security to future smart health services. IEEE Commun Mag 1–7. 10.1109/MCOM.019.2300122
4. Brink HW et al (2021) Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: a systematic literature review. Indoor Air 31(2):405–425
5. Barrett P et al (2019) The impact of school infrastructure on learning: a synthesis of the evidence. Technical report The World Bank Group, Washington DC, USA
6. Saini J et al (2020) A comprehensive review on indoor air quality monitoring systems for enhanced public health. Sustain Environ Res 30(1):1–12
7. ACTUA: anàlisi Contextual dels factors de mitigació de la Transmissió de la COVID19 a l'aUlA. https://actua-urv.cat/, (Catalan). Accessed 25 June 2023
8. Villanova O et al (2022) Sensing kit for the study of respiratory disease transmission in school classrooms. In: 11th international aerosol conference (IAC), p 825
9. Solanas A et al (2014) Smart health: a context-aware health paradigm within smart cities. IEEE Commun Mag 52(8):74–81
10. Batista E et al (2022) On the deployment of low-cost sensors to enable context-aware smart classrooms. In: Berta R, De Gloria A (eds) Applications in electronics pervading industry, environment and society (ApplePies), vol 1036. Lecture notes in electrical engineering. Springer, Cham, pp 333–338
11. Batista E et al (2021) Sensors for context-aware smart healthcare: a security perspective. Sensors 21(20):6886
12. Redmon J et al (2018) YOLOv3: an incremental improvement. arXiv:1804.02767