

# Improving Indoor Air Quality in Schools: The LEARN Project Approach

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Poor indoor air quality in schools poses a significant threat to children's health and cognitive development. With air pollution being a major contributor to millions of deaths annually, it is crucial to address indoor air quality issues, particularly concerning volatile organic compounds (VOCs) and ultrafine particles (UFPs). LEARN is a Horizon Europe project which aims to develop novel sensors to detect VOCs and UFPs, providing real-time monitoring of indoor air quality. LEARN measures and characterizes indoor and outdoor air pollutants and evaluates the presence of biomarkers of exposure and their effect on children's cognition, while also trying to recapitulate those effects using *C. elegans* as a biosensor. Additionally, advanced in vitro models of lung and skin will be utilized to assess the toxicity mechanisms of air pollutants. LEARN will generate evidence of indoor air quality in schools, including both chemical and microbiological determinants, across different parts of Europe. Three pilot studies will be conducted at schools in Belgium, Denmark and Greece. By evaluating exposure levels and implementing remediation strategies using high-performance filtering systems, this research seeks to unlock a large technological potential to significantly improve indoor air quality in schools.

Key words: Environment; Air Quality; Indoor Air Quality; Health; Impact; Monitoring; Schools; Europe

## 1. Introduction

The crucial factor that has a significant impact on the health of people, especially those who are at risk, is indoor air quality (Vilčeková et al., 2017). Indeed, indoor air quality is a critical factor that significantly influences public health, and particularly vulnerable population such as children (Mannan and Al-Ghamdi, 2021). Children are spending a significant part of their day in schools, where the quality of air can affect their health, cognitive development (Kaewrat et al., 2021; Sunyer et al., 2015), and overall well-being (Salthammer et al., 2016). It is a fact that poor indoor air quality in schools poses a significant threat to children's health and cognitive development, and overall well-being (Becerra et al., 2020; Wargocki et al., 2020). Despite its importance, Indoor Air Quality (IAQ) in schools is often suboptimal, exposing children to a range of pollutants that can affect their health and development (Baloch, 2020; Matthaios et al., 2022).

Children are especially vulnerable to the impact of poor air quality for several reasons (Costa et al., 2020). They are still developing their respiratory systems, which make them more vulnerable to damage caused by inhaled pollutants (Tanir and Mete, 2022). Compared to adults, children have a higher breathing rate relative to their body weight, which means they inhale more air pollutants per unit of body weight (Derbez et al., 2018; Fromme et al., 2008). Additionally, the immune system of children is not fully developed, and they are less able to fight pollutants (Sunyer et al., 2015).

In view of these challenges, there is a critical need for innovative solutions that provide accurate, real-time information on air quality (Abdul-Wahab et al., 2015). In order to implement effective remediation strategies and policies for the protection of children's health, these solutions should make it easier to interpret and apply data. The LEARN project "Development of Novel Assessments for Indoor Air Quality Monitoring and Impact on Children's Health" is an ambitious project under the Horizon Europe framework, specifically targeting the improvement of air quality in school environments and understanding its impact on the cognitive development of children (GA No.101057510). The project is investigating the impact of air quality on cognitive function and health of children aged from 9 to 12 years in schools across Europe. By developing and deploying innovative

sensors to detect harmful pollutants, such as volatile organic compounds and ultrafine particles, this project aims to overcome the limitations of existing air quality monitoring technologies.

In order to investigate the relationship between exposure to air pollutants and the cognitive development of students, a detailed cognitive study is being conducted to measure biomarkers of exposure and their correlation with cognitive function. The study will take place in Denmark, Belgium, and Greece and a number of 250 students of each country must participate in the study.

LEARN aims to establish a clear link between pollutant exposure and health metrics, providing evidence based for future policy recommendation, by correlating sensor data with health metrics. New sensors that can detect small concentration of air pollutants with excellent accuracy will be developed and deployed in order to overcome the limitations of existing technologies. These sensors will measure air quality in the school environment with real time data. Both indoor and outdoor environments will be assessed to provide a complete picture of exposure.

In order to study the mechanisms of toxicity caused by air pollutants, the research will use advanced in vitro models of human lung and skin tissues, together with a revolutionary multisensing device. This facilitates the understanding of the effects of these pollutants on children's health. LEARN also includes the implementation of remediation strategies, such as air filtration systems, to mitigate the identified risks.

Apart from this Introductory section, this paper is structured along three sections. The following section describes the LEARN approach, while section three is providing information on the expected outcomes of the LEARN project and its impacts and the last section summarizes the main conclusions.

## 2. The LEARN approach

LEARN is taking a multifaced approach to address the critical issue of indoor air quality in schools and its impact on children's health and cognitive development. This approach brings together cutting-edge technologies and strategic strategies for the protection of children's health (Figure 1).

LEARN evaluate the air quality and levels of exposure of children in schools in three different countries (Denmark, Belgium and Greece), where cohorts of children in the range of 9 to 12 years old will be recruited (Table 1). Air quality will be evaluated by measuring a wide range of chemicals, microbiological composition, and particulate matter, including Ultrafine Particles (UFPs), in air samples using standard methods. These measurements will serve as reference for the validation of novel sensors that will be developed to quantify concentrations of Volatile Organic Compounds (VOCs) and UFPs. In parallel, LEARN will evaluate the potential toxicity of selected air pollutants, using traditional and advanced in vitro models, such as organon-a-chip technologies to evaluate mechanisms of toxicity, and *in vivo* using *C. elegans* as a biosensor to evaluate potential neurological effects. LEARN's approach also includes a strategy of remediation using advanced and high-performance filtering systems.

Table 1: The LEARN Cohorts Campaigns

2.1.1. Cohort design	2.1.2. Information
2.1.3. Cohorts Location	2.1.4. Belgium, Greece and Denmark
2.1.5. School Grade	2.1.6. Primary/ basic schools, third to sixth grades
2.1.7. Children Age	2.1.8. 9-12 years old
2.1.9. # of Children	2.1.10. 990 (330 per each country)
2.1.11. Air Pollution Exposures	2.1.12. Ambient and indoor gaseous (e.g. CO, NO <sub>2</sub> , O <sub>3</sub> , VOCs, PAHs, etc.), as well as particulate pollutants (e.g. PM <sub>2.5</sub> , PM <sub>1</sub> , UFPs, etc.)
2.1.13. Outcomes	2.1.14. 5 cognitive function tests: the Stroop test and the following tests of the Neurobehavioral Evaluation System battery: Continuous Performance, Digit Span, Digit-Symbol, and Pattern Comparison
2.1.15. Covariates	2.1.16. Current and previous residence, family socioeconomic status, mother's education, out-of-school sport activities, family smoking behaviour, child's ethnicity, mode of transportation from and to the school, general health, mental condition

In this context, LEARN aims is to produce novel insights into the quality of indoor and outdoor air in both school and house environments and its health implications in children's health, and to generate new knowledge on environmental agents and pathogens to which children are exposed to on a daily basis. These include chemical and biological agents, such as indoor air microbiome and allergens, viral pathogens, household chemicals, UFPs and VOCs that populate the classrooms and the home environments.

To achieve such aim, heterogeneous data from multiple sources and sensing devices will be collected, including:

- traditional health records, as well as specific data from children aforementioned in Table 1, which will be mapped.
- novel personal marker reflecting the translocation of soot particles from lungs to organs and now for the first time used in a European wide study.
- data from on-the-shelf sensors and from new disruptive sensors targeting other environmental agents, both from indoor and outdoor environments, will be easily available and accessible through a user-friendly API.
- data resulting from the cross-validation between the sampling from the school cohorts and the laboratory *in vivo* and *in vitro* models.

All collected data will be orchestrated in a FAIR Data structure (findability, accessibility, interoperability, and reusability). This structure will be applied in a reachable and manageable way, creating a scalable network of knowledge that allows the extraction of valuable insights and novel guidelines and standards to apply the best practices for assessing IAQ and its impacts on the health of future generations (exposures, sources and risk factors).

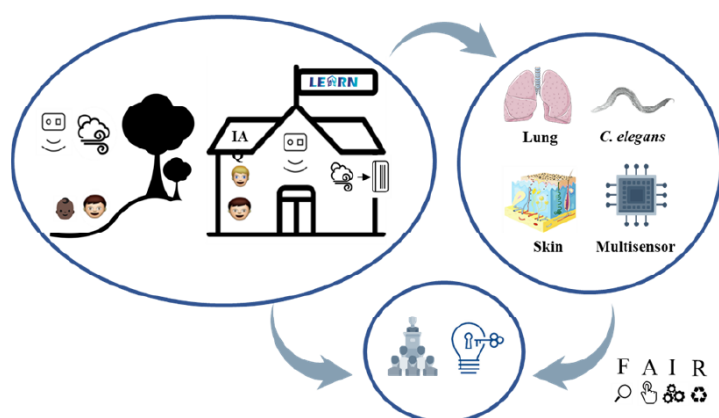


Figure 1: Representation of LEARN's proposed approach

The LEARN approach is structured around three dimensions Scientific, Technological and Societal (Table 2):

- **Development of Novel Sensors:** Innovative air quality sensors are being developed to measure UFPs and a selection of VOCs, aldehydes, and Polycyclic Aromatic Hydrocarbons (PAHs). These sensors are crucial for providing real-time, accurate data on indoor air quality in school environments.
- **Cohort Studies:** Cohorts in Belgium, Denmark, and Greece are being recruited to assess the exposure levels and health effects of indoor air pollutants on school children. These studies will provide valuable epidemiological data and help identify correlations between pollutant exposure and cognitive function.
- **Advanced *In Vitro* and *In Vivo* Models:** LEARN employs both traditional and advanced models to study the toxicological effects of indoor air pollutants. This includes the use of *C. elegans* as a biosensor for IAQ and the development of organ-on-a-chip models of lung and skin. These models allow for detailed investigations into the mechanisms of action of various pollutants and their potential health impacts.
- **Multisensing System:** Integration of a multisensing system for toxicological outcomes with the System on Chip (SoC) device. This system aims to provide comprehensive data on pollutant levels and their biological effects.
- **Air-Filtration Systems:** Implementing high-performance air-filtration systems in schools to reduce the concentration of harmful pollutants. These systems will be tested and optimized to ensure maximum efficiency and effectiveness in improving IAQ.
- **Policy Implementation and Stakeholder Engagement:** Developing and disseminating policies to relevant stakeholders, including academia, industry, regulatory authorities, and the general public. This includes organizing events and creating platforms to ensure the findings and recommendations of the LEARN project are widely accessible and implemented.
- **Data Management and FAIR Principles:** Ensuring that all data generated by the project is managed in accordance with the FAIR principles, making it available for future research and policy-making efforts.

Table 2: LEARN's concrete steps towards the three dimensions

Research / Scientific Approach	Innovation / Technological Approach	Societal Approach
Characterize the indoor and outdoor air pollution	Develop novel sensors for air quality related to UFPs and VOCs	Raise awareness of health impacts of IAQ in children
Evaluate exposure and behavioural effects of air pollutants in children attending school	Develop a protocol to use <i>C. elegans</i> as a biosensor to assess toxicity	FAIR Air Quality and Health Data Hub
Determine the biologic mechanisms related to the adverse effect of indoor air pollutants	Develop organ-on-a-chip models for lung and skin	
	Develop a multisensing device for toxicological applications and integration with SoC	
	Reduce and remediate the indoor air pollution	

The LEARN approach represents a comprehensive and innovative strategy to tackle the issue of indoor air quality in schools. Through advanced technology, rigorous scientific research, and proactive public health measures, LEARN seeks to create a safer and healthier environment for children, ensuring their well-being and optimal cognitive development.

### 3. Expected Outcomes

The LEARN project is expected to produce various significant outcomes that will help improve indoor air quality in schools and improve the health and cognitive development of children. These outcomes are diverse and demonstrate the LEARN's thorough strategy in addressing the problem of indoor air pollution (Table 3).

The key expected outcome of LEARN is to achieve significant improvements in IAQ in school environments. LEARN advanced sensors that provide real-time, accurate data on pollutants, such as UFPs and VOCs. This will allow for prompt actions to lower pollutant levels, thereby ensuring a healthier indoor environment for students.

Children will experience fewer respiratory issues and other health problems related to poor indoor air quality, since LEARN's approach focuses on lowering their exposure to harmful pollutants. This improvement in health is expected to contribute to improved well-being and cognitive function, as exposure to pollutants has been associated with cognitive development. Ultimate outcome of LEARN is to safeguard children from the negative impacts of indoor air pollution in order to support their physical and mental development.

Furthermore, new standards and recommendations for managing indoor air quality in educational environments will be established. The data and insights gained from LEARN's sensor deployments and cohort assessments will inform the development of evidence-based guidelines. These guidelines will offer a structure for schools to consistently monitor and improve air quality, guaranteeing the consistent implementation of best practices.

Moreover, the LEARN's technological progress will extend beyond the project's scope. The innovative sensor technologies created for monitoring UFPs and VOCs signify a major advancement in IAQ monitoring capabilities. These sensors are intended to be affordable and simple to implement, ensuring accessibility in various educational institutions and indoor spaces. The introduction of these technologies has the potential to transform the monitoring and management of indoor air quality, ultimately contributing to overall enhancements in public health. As LEARN project will produce extensive data aligned with the FAIR principles, this data will be beneficial for future research and policy development, facilitating ongoing progress in the indoor air quality field.

Table 3: LEARN's expected results towards the three dimensions

Research / Scientific	Innovation / Technological	Societal
Identification of body burdens resulting from multipollutant exposure and knowledge on their impact on children's health and wellbeing	New breakthrough technology on indoor air quality measurements with disruptive sensors; Patent registration of the new technology developed	In a post Covid19 era, new knowledge on importance of continuous air quality monitoring and its direct impacts and burdens on human body
New breakthrough scientific discovery on in vitro and in vivo model validation; deeper understanding on mechanisms of toxicity of selected air pollutants	Novel sensor technology for IAQ monitoring; In vitro and in vivo models	Direct contributions to new guidelines and standards in indoor environments
Successful large-scale demonstrator within the school cohorts: Cohorts with 3 schools in multiple geographies to validate the new sensor development and API	Up-take by schools: 3 European schools to adopt the new indoor air quality sensor technology during the project	Citizen's awareness of air quality

Lastly, LEARN project aims to create a long-term impact by encouraging greater understanding of indoor air quality concerns and promoting for collaborative efforts to address them, and in particularly through:

- Actively sharing information, such as engaging with policymakers, educators, and the wider community, the project aims to increase awareness and inspire change across various levels.
- Emphasizing the significance of indoor air quality and offering practical solutions, the project enables stakeholders to take effective measures to enhance air quality in schools and other indoor spaces.

#### 4. Conclusions

The LEARN project, recognizing the critical need to protect children's health and support their cognitive development, is at the forefront of efforts towards improving indoor air quality in schools. LEARN is well equipped to address the complex challenges posed by indoor air pollutants by adopting an integrated approach combining cutting edge sensor technology, through toxicological studied and strong public health strategies.

Moreover, LEARN demonstrates a holistic and innovative approach to addressing the critical issue of indoor air quality in schools. LEARN aims to create a healthier learning environment for children through the integration of advanced technology, scientific research and effective public health interventions. With its approach LEARN will not only work to improve the immediate well-being of the school children, but also to lay down new standards for monitoring and management of indoor air quality, which could have a wider impact on policies and practices. LEARN contributes to the development of a healthier and more informed future generation by focusing on children's health and cognitive development.

The method used by LEARN also highlights the significance of making a societal impact by actively implementing policies and involving stakeholders. Through sharing research findings and recommendations with policymaker and educator, LEARN increases awareness and encourages collaborative efforts to enhance indoor air quality. Utilizing FAIR principles -findability, accessibility, interoperability, and reusability- for data management guarantees that the information produced by the project can be easily accessed and utilized for future research and policy-making endeavours.

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