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A Service-Learning Experience in Secondary Education to Promote STEM Learning Through Collaboration Between Research and Education Centers

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ABSTRACT

The needs of the digital revolution and the knowledge-based economy impose a transformation of traditional education to improve technical and scientific knowledge and include alternative abilities. This work presents a service-learning initiative with multiple goals: to improve scientific, technical, engineering, and mathematic (STEM) knowledge at school, to enhance students' engagement, and to make people aware of the repercussions of poor indoor air quality. The initiative involves four actors: the administration which steers the initiative, students who are the receivers of the knowledge, teachers as facilitators of the activity and research centers as expert references. Within this service-learning initiative, a real-life project has been proposed, focusing on measuring carbon dioxide (CO_2) levels in classrooms and correlating them with indoor airborne infection transmission. Reference experts have developed two systems provided to teachers and students for project implementation. The project involves an engineering step where students set up the systems, and a scientific step where students hypothesize, develop experiments, analyse data, and communicate results gaining experience with the scientific method. Through the combined efforts and appropriate allocation of responsibilities, this experience has yielded excellent results in STEM knowledge transmission and has proven effective in fostering student commitment to their learning process.

Keywords: service learning, collaborative learning, project-based learning, scientific learning, engineering learning

INTRODUCTION

Over the past decades, the digital revolution and the knowledge-based economy have brought about a paradigm shift in our society with respect to traditional-based economy societies. Nowadays, knowledge, information and communication technologies have become fundamental pillars of most of our economic and cultural activities and the knowledge economy has become the main source of growth and competitiveness in the more economically developed countries (Hadad, 2017; Lisbon European Council 23-24 March 2000, 2000). This new paradigm demands skilled workers with solid knowledge base, technology ecosystems prepared for continuous creation and dissemination of knowledge, means and tools for the rapid acquisition of technical competencies, as well as people with the ability to self-learn, work collaboratively, and seek knowledge from different sources. They should be capable of developing critical thinking and possess strong communication and social skills, among other abilities. Educational institutions as well as educational actors, scientists, and pedagogues, should play an important role in building and supporting this new paradigm, but traditional teaching systems are not fast enough and fully able to cover all the exposed needs. Usually, the abilities and tools that the digital revolution and knowledge-based economy demand are not always included in regulated education programs and many users are forced to learn and acquire them autonomously outside school/academia. Furthermore, a paradox is occurring in western countries where, although there is an increasing demand for STEM competencies (Science, Technology, Engineering and Mathematics) (Carlisle and Weaver, 2018; Stehle and Peters-Burton, 2019), there is also a decline in the number of students pursuing science and engineering vocations (Arnoux et al., 2009; Becker, 2010; Convert, 2005; Habig et al., 2020). To stimulate a faster evolution of education and to promote STEM vocations, an increasing interest in changing traditional learning systems and designing new teaching-learning strategies is emerging. Certainly, traditional education, mainly based on teacher-centered methods, is built on the idea that teachers are experts that transmit their knowledge to students. If students are engaged, this is an efficient method to pass information from a single source of knowledge, the teacher, to many receivers, the students. Teachers often assume that students are committed to learning by default, and as a result, they tend to adopt the unidirectional transmission of knowledge as their main teaching tool. They feel reluctant to change the method and diversify the sources of knowledge because they feel, among other things, that could undermine his authority. However, this one-way procedure promotes passive learning and does not promote critical thinking, does not encourage seeking and enriching knowledge with a diversity of information sources, does not teach how to be an autonomous learner, does not animate to mobilize different resources to solve tasks, does not promote collaborative work, does not help to share and organize responsibilities and tasks, does not lead to improve communication and social skills, does not promote innovation, and, actually, student engagement with the learning process is poor and depends mainly on the teachers' motivational abilities (Brand, 2020; Collins and Halverson, 2009; Laal and Ghodsi, 2012; Leite, 2017; Mergendoller et al., 2006; Song et al., 2011; Stephan, 2020).

To promote the acquisition of these skills and to increase the engagement of students, slowly but steadily, education is experiencing a great transformation moving the focus of the process from the teacher to the student. For some years now, educational administration, pedagogues and educational institutions have been working together to implement new educational policies and methodologies that help to achieve this goal. Several alternative learning methodologies such as the flipped classroom, small group instruction, service learning, project-based learning, problem-based learning, game-based learning, and collaborative learning, among others, have appeared, and are being studied and tested by educational researchers. Although the different strategies have advantages and disadvantages and their application depends on the specific educational environment, there is a certain consensus from educational research that the learning-centered strategies can better promote, on the new millennium learners, the engagement, skills, and competencies needed to live in today's knowledge-based society (Amerstorfer and Freiin von Münster-Kistner, 2021; Bell, 2010; Cain and Cocco, 2013; Collins and Halverson, 2009; Cornell and Clarke, 1999; Saavedra and Opfer, 2012; Kaldi et al., 2011; Laal and Ghodsi, 2012; Lafuente Martínez, 2019; Mergendoller et al., 2006; Peterson et al., 2018; Song et al., 2011; Stehle and Peters-Burton, 2019; Stephan, 2020; Trilling and Fadel, 2012).

This paper presents a novel service-learning initiative that consists of the implementation of a project-based collaborative learning project at secondary schools using the combined efforts of four contributors: the local education administration, teachers at school, reference experts, and students. Collaboration between schools and expert university researchers can be an essential link in reinforcing education, particularly in STEM learning at schools. However, despite its potential, this type of partnership has received little attention, and as far as we know, has not been studied in the context of service learning (Baker and Galanti, 2017; Burton and Greher, 2007). This highlights a significant gap in the existing literature regarding the exploration of such collaborative endeavours in service learning that this paper seeks to address. Two research centers of reference and ten schools have been involved in this initiative aimed at engaging 15–16-year-old students in STEM learning while also seeking for increasing science and engineering vocation, improving general engagement, and fostering teamwork. This initiative is part of a service-learning program of the Catalan administration named "Recerca, creació i servei" (research, creation, and services) and its aim is to promote learning competencies by collaboratively solving challenging projects proposed by entities outside the school. In the case of this work, the Department of Electronics and Biomedical Engineering of the Universitat de Barcelona jointly with the Institute for Bioengineering of Catalonia are in charge of proposing a scientific-technological challenge that students at school should solve. Details of the challenge will be explained in detail below. Under this initiative, the administration is a general and high-level supervisor of the project. Its role is to organize and coordinate periodic meetings to monitor the process and to finance the costs of the process. The researchers of the research center adopt the role of reference experts for scientific and engineering issues. Researchers supervise and validate the process at a deeper level, and they are responsible for providing useful tools and solving scientific and technical problems. Therefore, teachers are relieved from being reference specialists, and they become the facilitators of the project. They concentrate their task on controlling the dynamics of the project, organizing groups, directly guiding the initiatives of the students, animating them to look for sources of knowledge, advising and validating their experiments at a broad level, following their interactions, promoting social skills, and fostering rigorous and effective communication. Finally, the students are the developers of the project using the tools provided by the experts, and they are the responsible for the outcomes. All these combined efforts can be assessed concerning the answers to the specific research questions explored in this initiative. In summary, these questions inquire whether the method has effectively enhanced student engagement and cultivated their interest in science and engineering, whether students acquire new scientific and technical concepts through the method, and furthermore, whether students perceive the usefulness of this method in their learning process.

METHODS

The general framework of the initiative is a service-learning project (Anderson et al., 2019; Bringle et al., 2006; Felten and Clayton, 2011; Filges et al., 2022; Kuh, 2008). Service-learning is an instructional strategy that provides students with the opportunity to have direct experience in solving real-world practical problems in their community. Service learning introduces added value to community service and volunteering. In service-learning activity, students learn from real scenarios and connect the service activity with their curriculum and the contents of their regular academic course. In that way, service learning broadens students' vision, promotes their engagement, and enhances their personal values. Several teaching-learning methodologies can be used to implement a service-learning experience (Calarasu et al., 2020). In this work, we use a project based collaborative teaching method steered by a community-based research team composed of students, teachers, experts, and the administration. Every partner of the community-based research team has its own role, but they all collaborate and contribute equally to the success of the experience.

Project-based learning is a student-centered teaching method in which students learn by developing feasible solutions for specific projects. Project-based learning is directly connected to the constructivist learning philosophy that postulates that knowledge is not innate, it cannot be passively absorbed and, on the contrary, it must be built from an active attitude and from previous knowledge and experiences. Project-based learning is progressively gaining importance in education curricula due to its capacity to enhance the student's engagement, generate a greater understanding of knowledge, promote creativity and critical thinking, and improve social skills (Bell, 2010; Blumenfeld et al., 1991; Kokotsaki et al., 2016; Lafuente Martínez, 2019; Ljung-Djärf et al., 2014; Wan et al., 2022).

But for these capacities to be successful, it is necessary that some boundary conditions are also met. Creativity and critical thinking are lost if project-based learning is applied as a rigid recipe based on always following just the same few steps. To promote the students' engagement, it is also important to give the project a challenging and real-world context. Students should feel that the project is of real interest and with potential implications beyond obtaining a mark. Moreover, it is also important to leave students to make their own decisions about the pathway for completing the project. In that way, they will be more interested and involved in the development of the project and in their outcomes (Al-Balushi and Al-Aamri, 2014; Bell, 2010; Wurdinger et al., 2007).

Regarding the practical application of the methodology, there is no restriction using project-based learning methodology implemented for a single student, but to improve communication, teamwork, and social skills, the most suitable implementation is in small groups of students who collaborate. Collaborative work also helps to engage students, to move the project forward, and to promote sharing of knowledge and expertise. Under a collaborative project learning strategy, two or more students elaborate viable solutions to the project while respecting each individual contribution. The exposure of students to different perspectives and diverse insights facilitates the development of social and teamworking abilities in a natural way (Cohen, 1994; Davidson and Major, 2014; Sandland et al., 2020).

But collaborative working is not just to group students. Some preventions should be taken to avoid unwanted but common student attitudes such as relying the work on one or two teammates while the others passively wait for the final grade or doing the job as a final compilation of small parts without sharing knowledge or undermining the work of teammates by eager students in search of the best grade. The development of a previous student's project plan, supervision of the task's assignments and the periodical check of the progress of the project are tools that teachers should use to prevent these bad attitudes.

Project Definition

In 2021, as an initiative of the Catalan Education Counselling and promoted by the General Directorate of Inclusive Education, a specific service-learning innovation program for secondary schools (from 12 to 16 years old) named "Research, creation and service program" began. This program promotes the acquisition of

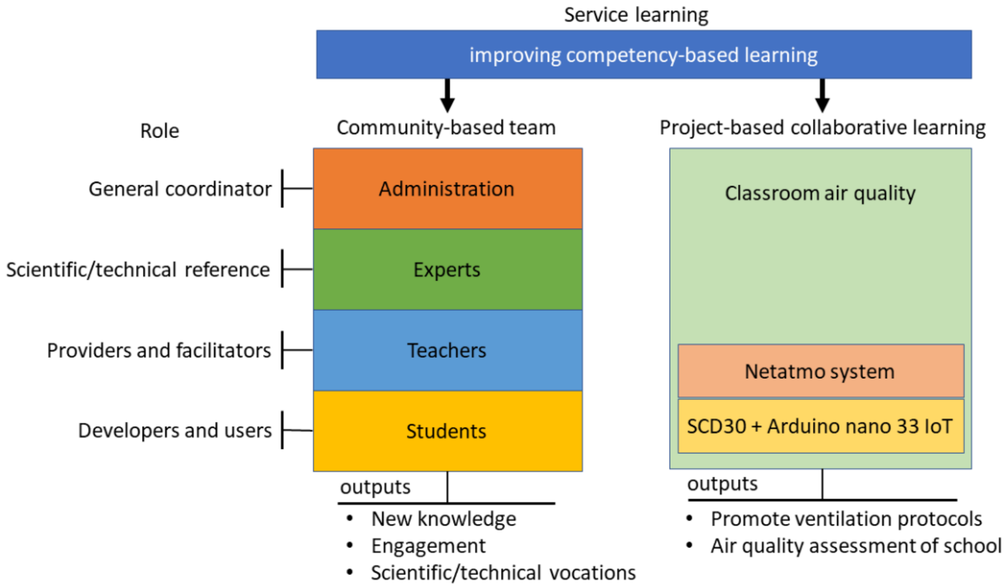

Figure 1. Schematic summary of the service-learning initiative (includes the team with their role, the project with the hardware, and a short list of expected outputs)

competencies through challenges derived from needs raised by local entities, which are materialized in the elaboration of cultural products, projects, and services. A variety of entities (museums, local associations, NGOs, research centers, …) can propose projects from different fields (social, artistic, scientific-technical, communications, …) aimed at secondary school students. In the case of this current paper, the project is specifically aimed at students in their last year of secondary education, who are 15 or 16 years old. The Catalan education system allocates a subject of 4 hours per week to project development of any scope, across all secondary education levels. The proposed service-learning project fits within these hours, ensuring no disruption to routines and compatibility with the regular and formal assessment practices. The specific proposal has been suggested and supervised by both the Institute for Bioengineering of Catalonia (IBEC) and the Universitat de Barcelona (UB). It consists of the assessment of the air quality in classrooms by measuring mainly the indoor CO_2 concentration. The underlying idea is related to the concern about the transmission of COVID-19 (or any other airborne disease) in the classroom. It is known that poor air quality and high values of CO_2 concentration are correlated with poor ventilation and therefore, also correlated with a greater probability of disease transmission (Kappelt et al., 2021; Rudnick and Milton, 2003; Schade et al., 2021). Following the preventions exposed for improving engagement and science and engineering vocations, the project relates to a real-life problem, it is affordable but challenging and it connects students with useful technology that they normally do not use at the school. **Figure 1** shows a schematic diagram of the whole initiative with a short list of expected outputs.

Project Steps

At a practical level, the project includes two steps: an engineering step to set up the systems and a scientific step to design experiments and analyse results. The required hardware and software material for the whole project is detailed in **Table 1**.

It is worth mentioning that this project could also be easily adapted to an autonomous project format with minimal remote supervision, with the aim of overcoming the disadvantages of small educational communities, far from large metropolitan areas, where the cost per capita of education is high and the difficulties to access specialized contents and advanced educational resources are great (Lavalley, 2018).

The engineering step

As tools for working in this challenge, the project includes two different measuring systems:

1. The smart home weather station from NETATMO® which is a closed commercial system that includes modules and sensors for measuring indoor and outdoor temperature and humidity, outdoor atmospheric pressure, and indoor CO_2 concentration and sound pressure.
2. A system based on the connection of the SCD30 sensor module from Sensirion® and an Arduino 33 IoT nano. The SCD30 sensor module integrates a NDIR sensor for measuring CO_2 and it also incorporates a temperature and humidity sensor. Its digital interface is compatible with the I2C protocol. The whole device (SCD30 + Arduino 33iot nano) is an open system that must be ensembled (**Figure 2**).

Table 1. List and description of material

Hardware	Description
Smart home weather station from Netatmo®	Commercial system. Measures outdoor weather magnitudes and indoor air quality magnitudes.
Arduino 33 IoT nano	Open-source prototyping platform for electronic design, based on SAMD21 Cortex®-M0 microcontroller.
SCD30 Sensor from Sensirion®	NDIR-based CO_2 sensor system with integrated temperature and humidity sensors.
microUSB-USB cable	Arduino-computer connection cable.
working Kit	Protoboard, cables, …
A computer	Necessary to develop the software, set up systems, configure dashboards, and analyse and visualize results.
A smart phone (optional)	Optional to set up Netatmo® system. Requires Netatmo free app be installed.
Software	**Description**
Arduino IDE	Open-source software to develop the Arduino code.
Thingher.io open-source IoTcloud platform	An account at thinger.io is needed to transmit data from SCD30-based system to the thinger.io cloud.
Netatmo® cloud platform	An account at Netatmo® is needed to transmit data from the Netatmo system to the Netatmo cloud.
Netatmo® smartphone app (optional)	It is used to configure the Netatmo system and to visualize data.

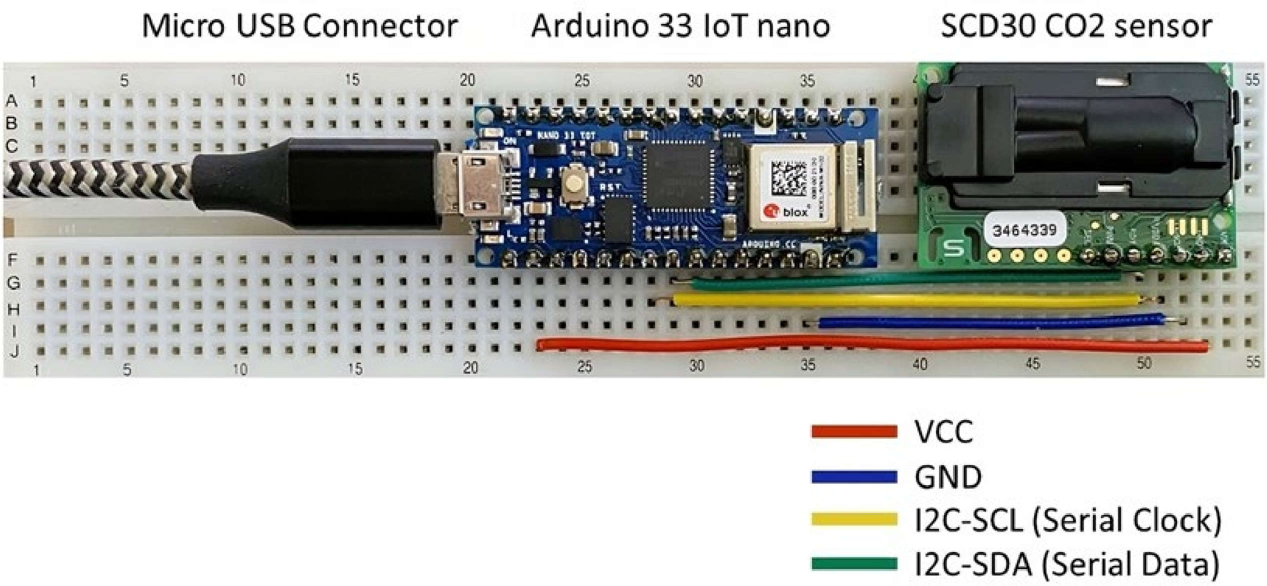

Figure 2. CO_2 measuring system based on the SCD30 Sensirion® sensor and an Arduino 33IoT nano

Both systems have wireless connectivity capabilities. The Netatmo weather station transmits data to a smartphone through a free app, and to a web dashboard that can be accessed with a Netatmo private account. The dashboard is configurable by the user and graphics of all the variables can be visualized. The system measures and transmits data every 5 min, and it also provides means to download measured data in CSV or XLS file format. The system based on the Arduino 33 IoT nano can be connected to a cloud Internet of Things (IoT) platform using specific libraries. The open-source platform thinger.io has been selected to perform this functionality. The first step with the sensor module and Arduino consists in connecting both devices and perform local measurements of CO_2, temperature, and humidity. The second step consists in developing the connexion between the local device and the IoT platform. Arduino has specific libraries and software drivers for developing the software and perform both steps properly (**Figure 3**).

The role of the experts at this step is to develop of a useful final solution, to fine-tuning the instruments and equipment, to generate documentation and to train teachers so that they also have the basic technical ability in the project. Experts are also responsible for the compilation of all the material and their distribution to teachers. During the normal development of the project, experts are the reference for any technical issue. It is important to note that experts involved in the current project are also university-level teachers, possessing pedagogical abilities to effectively communicate scientific and technical information at all teaching levels. Furthermore, all supporting materials were reviewed by the general coordinator, who possesses the criteria and capability to adjust the contents of the material to the appropriate level if necessary.

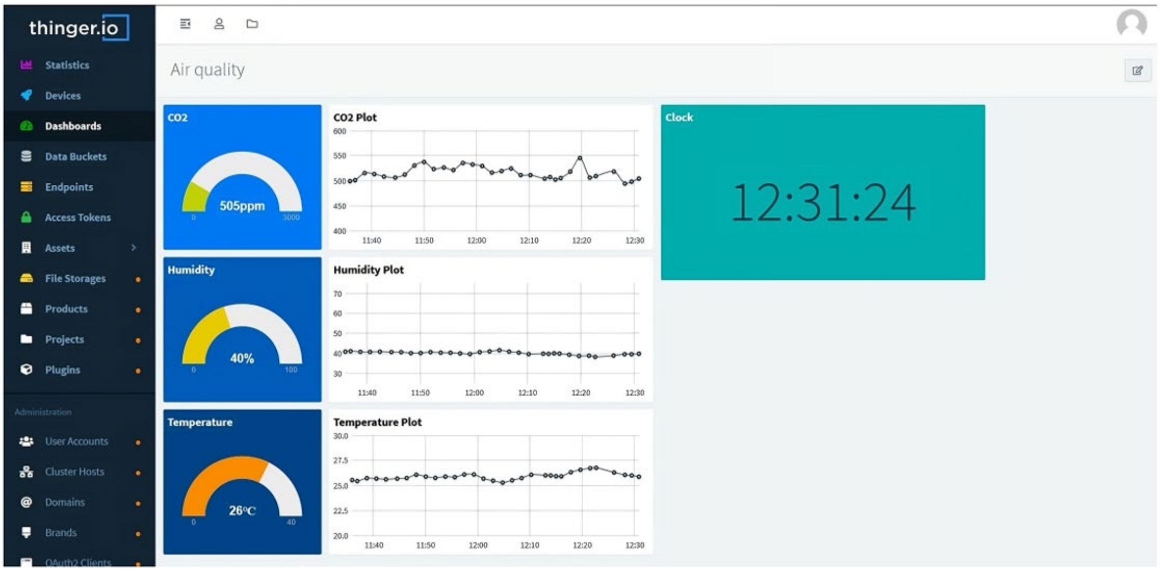

Figure 3. Example of a thinger.io dashboard developed to receive and visualize the CO_2, humidity, and temperature measurements provided by an SCD30 sensor connected to an Arduino 33IoT nano

The role of the teachers at this step is to attend the training course and be able to mount the final solution with the guidance of the experts. They are in charge of transmitting this knowledge in a practical way to students and they are also responsible for the custody of the material. They design the student's working groups and they supervise their dynamics. During the normal development of the project, teachers are facilitators of the process, solving simple technical problems and transferring the blocking difficulties to the experts. It is also important to note that the participating teachers possess background in STEM disciplines, thereby closely aligning with the project's requirements.

The role of the students at this step is to set up the systems with the help of teachers, to upload and download experimental data, and to validate the correct functionality of all. This step is likely the first time that students have such close contact with electronic technology, sensors, microcontrollers, and wireless communications. Setting up the systems and measuring, students lose their fear of interacting with advanced systems and have the opportunity to understand useful and transversal engineering and technical concepts such as measurement synchronization, noise, calibration, validation, or correlation among others.

The scientific step

Once the setup of the systems is completed, the scientific step begins. The general task of the scientific part of the project is to measure CO_2 concentration, but to favour the commitment, students can decide a specific project in the context of CO_2 measurement. The suggested project by the experts is the measurement of air quality indoors but it is not mandatory to perform it. Students can shift the focus towards alternative goals, while still keeping the CO_2 measurement as the main objective, and decide on the pathway to complete the tasks. Using the provided material, students must follow the scientific method. They should formulate hypothesis, perform experiments to collect useful data, and analyse the collected datasets to validate or refuse their hypothesis. To enhance the scientific communication skills, at the end of the project, short presentations and posters should be prepared and presented to communicate results and conclusions.

The role of the students in this step is to formulate the hypothesis, to lead the experimental work, to analyse data, and draw conclusions. They are also responsible for generating scientific reports to expose results and the final conclusions of their experiments. In that way, students learn to follow the scientific method in a practical scenario. The role of the teachers in this step is to be a provider, supervising and advising on the hypothesis of the students, answering simple scientific questions, providing means, and helping and guiding the development of the experiments. In addition, they must be attentive to maintaining the commitment of the students throughout the development of the project. The role of the experts in this step is to be a reference. They can validate or reject student proposals, warn of difficulties, answer difficult scientific questions if required, and give advice on problems that may arise. They should also help teachers maintain the engagement of students along the project. Finally, they act as jury for the final scientific communications of the students.

At the beginning and at the end of the project, students answer a questionnaire about different methodological, scientific, and technical issues. In that way, it is possible to assess the improvement in the knowledge that students gained. Regarding the scientific and technical issues, both, the initial and the final questionnaires include the same technical questions, to measure and compare both the initial and final levels of the students.

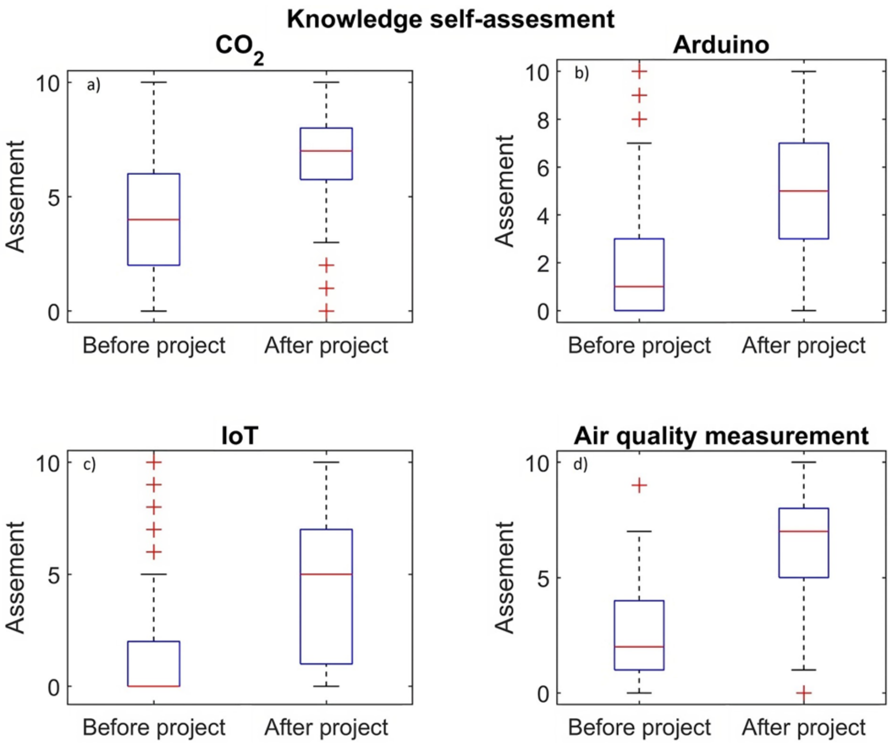

Figure 4. Statistical analysis of student's self-assessments: (a) Boxplot of the assessment of the knowledge of how CO_2 is measured, before and after the completion of the project, (b) Boxplot of the assessment of the knowledge of how Arduino works, before and after the completion of the project, (c) Boxplot of the assessment of what IoT is, before and after the completion of the project, (d) Boxplot of the assessment of the knowledge of how air quality can be measured, before and after the completion of the project

Table 2. Median and confidence intervals of the self-assessments

	Before		After	
	Median	**CI (99%)**	**Median**	**CI (99%)**
CO_2 measurement	4	[3.18, 4.82]	7	[6.33, 7.67]
Arduino	1	[0.15, 1.85]	5	[4.04, 5.96]
IoT	0	[-0.80, 0.80]	5	[3.89, 6.11]
Air quality	2	[1.29, 2.73]	7	[6.13, 7.87]

RESULTS

To date, the total amount of students involved in this initiative has been 225. The number of students who answered the initial questionnaire was 111 and 98 students answered the final one.

The technical questions include a self-assessment of technical knowledge and two basic but specific questions. About the self-assessment, students are asked to assess, with a number between 0 (minimum knowledge) and 10 (maximum knowledge), their knowledge about four general issues: CO_2 measurement, Arduino based systems, IoT and air quality. They should do the assessments before initiating the project and after the end of the project.

Figure 4 and Table 2 present a statistical analysis of the student's self-assessments.

A statistical Wilcoxon test for equal medians has been performed for the four assessments, and in all cases the tests indicate that the medians of the answers before and after each of the assessments are different at a significance level of 0.05.

Regarding the specific technical question, students answered two basic technical multiple-choice questions, before and after the project. The two basic questions were:

1. Do you know what 1 ppm is?
2. Which is the common technology used in CO_2 gas sensors?

Table 3. Percentage of correct answers to the specific technical questions and their confidence intervals, before and after the completion of the project

	Before		After	
	Correct answer percentage	CI	Correct answer percentage	CI
1 ppm	51.3%	[41.7%, 60.9%]	74.2%	[64.3%, 82.6%]
CO_2 sensor technology	10.8%	[5.7%, 18.1%]	35.0%	[25.6%, 45.4%]

Table 3 shows the percentage of correct answers and the confidence interval (CI) (95% confidence).

To assess the engagement that the students have had with this project, they have been asked to evaluate if they enjoyed participating the project. The allowed marks should be between 1 (lower mark) and 5 (greatest mask). 80 students answered this question. The median value was 3.5 and its 95% confidence interval is (3.0 – 4.0).

As service to the community, from the several positive outputs of this service-learning initiative, two should be highlighted. Through the experiments designed by the students, the experts have had the opportunity to test the performance and robustness of the new SCD30 sensor from Sensirion®, launched onto the market in 2020. This knowledge, acquired in a real scenario, is a proof of the viability of the sensor that experts can use for their research projects and for their university teaching tasks. Moreover, as a service to the education centers, several works developed by the students have demonstrated that indoor air quality in some small, crowded classrooms of their schools deteriorates rapidly under poor ventilation conditions. Teachers have expressed their intention to share these results with the school councils, with the aim of restricting the long-term usage of such spaces and improving the ventilation protocols.

DISCUSSION

From the final expositions of the students, it can be said that the students' contributions have been numerous and varied. Beyond the technical knowledge that the students have acquired, they have demonstrated great initiative in the generation of hypotheses and the development of experiments. In that development, the students have used both the commercial NETATMO instrument and the one developed on Arduino. The choice between one or the other has depended more on the versatility provided by the instrument for each of the experiments. As an example, the following is a short list of hypotheses and research questions proposed by the students:

- Does the air quality in the classroom depend on the ventilation/number of people inside?
- Has the reform of the dressing room improved the air quality in it?
- Is the CO_2 level in the classroom higher after doing exercise?
- Can we measure the change of CO_2 levels during photosynthesis?
- Can we distinguish different cola drinks by the CO_2 they emit?
- Does a hybrid car emit less CO_2 than a benzine petrol car?

One goal of the project is to test whether the combination of efforts of experts, teachers, students, and administration has been useful for gaining new scientific and technical knowledge. From the statistical analysis of the answered tests, it can be said that students have the perception that they have gained knowledge in all the fields asked about (CO_2 measurement, Arduino-based systems, Internet of Things, and air quality assessment). **Table 2** shows that the median value of the self-assessments of students before and after regarding their knowledge of CO_2 measurement increases by 3 points on a scale from 0 to 10. The increase in Arduino is 4 points, and the Internet of Things and air quality assessment show an increment of 5 points. It can be highlighted that before the project none of the asked self-assessments reached the minimum passing mark (5 over 10) while after the project all the self-assessments received the minimum passing mark or greater. **Table 2** also shows that the confidence intervals between before and after do not overlap and the statistical significance analysis indicates that these results are robust and cannot be obtained by chance. Beyond the student's perception, the performed test about specific technical questions is also statistically significant and show that students have really learnt some new scientific knowledge. As it is shown in **Table 3**, before the project only half of the students knew what a ppm is, and after the project three quarters of the students knew it. Again, confidence intervals do not overlap, indicating that the results are robust. A similar discussion can be done about the CO_2 sensor technology knowledge, that goes from a scant 10% of correct answers before the realization of the project to a 35% after the project.

Regarding the engagement of the students with that kind of project it can be said that a mark of 3.5 of median in a scale between 1 and 5 with a confidence interval between 3 and 4, can be considered a remarkable result, halfway between normal engagement and very good engagement. Additionally, the teachers involved in the project declare that it has been useful in several ways: as a guidance for students of the path to follow in a future scientific/technical career, as a motivator to activate students who were passive in class, and as a positive influence on the promotion of scientific/technical vocations. In that last sense, from the comments collected from 65 students, 18 of them (27%) declare specifically that after the project they are more interested in science and engineering issues. While this initiative appears to yield positive results, it is important to acknowledge the limitations of the study. The current study focuses solely on comparing outcomes before and after implementing our particular and specific approach. There is a general consensus that new learning methods, such as service learning and project-based methods, foster deeper engagement and more meaningful learning by linking academic content with real-world experiences. However, traditional lecture-based learning may also be highly efficient in transmitting specific knowledge. The choice between these different approaches will depend on heterogeneous factors such as educational objectives, educator preferences, social contexts, etc. This contribution highlights that the presented service-learning initiative, implemented through a project-based collaborative teaching method, can be a valuable approach. However, conducting a comparative analysis to assess our current results against other approaches requires specific experiments that, unfortunately, are beyond the scope of this contribution.

CONCLUSIONS

This work reports a service-learning initiative organized as a collaborative project-based learning experience done at secondary schools in Catalonia. This initiative is part of the specific learning innovation program for secondary schools named "Research, creation and service program". A community-based research team with the sum of efforts of four contributors has steered this service-learning initiative. The four contributors are administration, experts, teachers, and students. Experts and teachers take the initiative of the project dividing their responsibilities: experts are the scientific and technical reference; teachers are the providers and guides of the project. Administration is the financer and general supervisor of the project and, of course, students are the subject of the learning process. The distribution of responsibilities allows contributors to focus on developing the tasks in which they have experience and leave the other tasks to their partners. This sum of efforts and partition of responsibilities has shown good performance and has provided excellent results. The statistical analysis of the questionnaires answered by the students indicates that the scientific and technical knowledge exposed to the students has been understood and acquired. Most of the students have the perception that they have learnt, and the test confirms this perception with confidence. To improve engagement, a challenging and real-world connected project is needed. This task is in the hands of experts who, in this first experience, have proposed a project related with air-quality measurements and its relationship with the transmission of airborne infections such as COVID-19. However, a certain degree of freedom has been allowed for the hypotheses and experiments that students can propose, which at the end redounds in the improvement of the student's engagement. Again, the statistical analysis of the questions conducted to assess the engagement indicates that the engagement of the students has been good to very good. Although the pedagogical improvement is the most significant outcome of this service-learning initiative, there are several additional positive outcomes. As a service for the centers, student measurements, assessments, and conclusions about indoor air quality will be used in the future by schools to improve their classroom ventilation protocols. As a service for the community, the initiative has provided an opportunity for experts to test new and advanced sensors in real scenarios and the knowledge obtained will be applied in new scientific/engineering projects and used in teaching activities at the university.

To date, and as far as we know, the service-learning initiative presented in this work has been the first successful attempt to combine the efforts of administration, teachers, and research centers for providing an improvement in students' STEM learning process. The extension of this initiative over the next two years will allow us to corroborate these initial results based on a first 1-year experience. While results and statistical analysis demonstrate the value of the presented service-learning initiative, the study solely focuses on comparing the results before and after implementing the specific approach. Conducting a comparative analysis with other approaches is beyond the scope of this contribution and remains a pending issue.

LIST OF ABBREVIATIONS

STEM: Science, Engineering, Technology, and Mathematics
NGOs: Non-Governmental Organizations
IBEC: Institut de BioEnginyeria de Catalunya
UB: Universitat de Barcelona
NDIR: Non-Dispersive InfraRed
CI: Confidence interval
IoT: Internet of Things
ppm: parts per million

DECLARATIONS

Competing interests: The authors declare that they have no competing interest.

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