Effective Synergies at Technical Universities to Actively Promote STEM at K-12 Schools

Jorge Torres Gómez*, *Senior Member, IEEE*, Nicolai Spicher†, *Member, IEEE*, and Jan Haase‡, *Senior Member, IEEE*
*School of Electrical Engineering and Computer Science, TU Berlin, Berlin, Germany
†University Medical Center Göttingen, Germany
‡NORDAKADEMIE gAG Hochschule der Wirtschaft, Elmshorn, Germany
* jorge.torresgomez@ieee.org, † nicolai.spicher@ieee.org, ‡ janhaase@ieee.org

***Abstract*—Promoting science, technology, engineering and mathematics (STEM) education at K-12 level motivates pupils to pursue technical careers at universities, which is of high importance due to skilled labor shortage and other factors. In particular, in Germany the population with a tertiary education level is less than the average in the European Union (35–41 %. Motivating the study of technical careers, this paper features a model for promoting STEM at the K-12 education level by developing joint teaching platforms with students at technical universities. The model is derived from hands-on experience at TU Berlin targeting a climate change topic: As part of student semester projects, Bachelor students integrated a humidity sensor into a drone and conducted atmospheric measurements. The resulting hard and software components provided by the students allowed the preparation of a lesson plan to promote STEM at the K-12 level. In this way, we synergically connect the means from the university with hands-on activities as means to promote STEM topics with K-12 students. The resulting benefits are manifold; students at the university develop technical skills and become part of a social intention to promote STEM topics on the one hand. On the second hand, pre-university students might have first-hand experiences with hardware prototypes and their applicability to relevant topics like climate change surveillance. The developed model may illustrate straightforward means for educators to design lesson plans, including actual practices at university and pre-university levels.**

***Index Terms*—K-12, STEM Education Initiatives, Teaching Strategies, Universities.**

I. Introduction

Actively promoting STEM at the K-12 educational level is naturally conveyed while resorting capacities at technical universities. For instance, students in bachelor's and master's courses in engineering and computer science develop quite sophisticated products as part of their academic programs [1]. These products are in the form of software interfaces and hardware components, which can be of later application to plan for hands-on activities at the K-12 level. Such directions capitalize on the rich development environment at technical universities for the much-needed introduction of STEM topics at K-12 [2].

Thoroughly leveraging these technical solutions, this paper illustrates a plan to reuse these capacities to develop a teaching plan for K-12 students. The teaching plan aims to develop hands-on activities for students at the pre-university level to promote STEM topics. Although we develop a plan to support computational thinking mainly [3], we also illustrate with a methodology a path to extend it to other engineering branches.

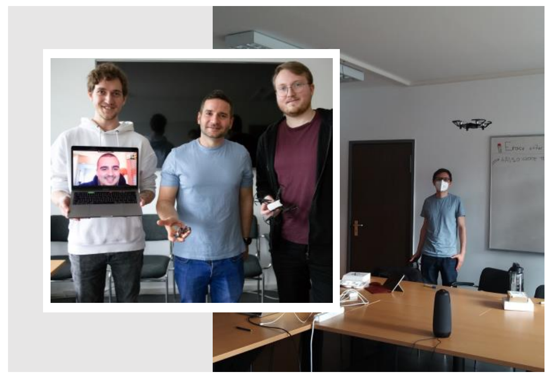

Fig. 1: Experience with students developing drone-based monitoring technologies.

We chose to develop this strategy around the tender movement for climate protection. This is a topic of wider understanding and with an increasing trend in developing supporting technologies. Nowadays, the press illustrates the applicability of technologies for climate protection like the use of drones to increase the population of trees in the forest [4], or the biotechnology engineer of crops to increase their ability to capture increasing levels of CO_2 [5].

Elaborating on the climate topic, our conception is to link the development of university technical projects with readying hands-on lessons. To illustrate this conception, we target a monitoring application for urban trees, directly connected with climate surveillance. We plan for students at the university to build up a platform to operate a drone and measure the biomass levels of trees. This technical solution will provide a basis for designing hands-on activities with pre-university students later.

We had a praiseful previous experience with this conception. As illustrated in Fig. 1, we supervised a team of students at the university that developed a drone-based humidity sensor. This was later used to design a lesson plan for hands-on activities at K-12, see the motivations in the published paper [1]. This experience illustrated an educational methodology that reuses means (naturally developed at technical universities) to promote STEM topics with the active participation of students at both educational levels, i.e., university and K-12.

Promoting STEM becomes quite constructive in Germany, where the average population with tertiary education level is less than the average in the European Union (35.7 % to 41.2 % for 2021) [6]. Besides, at universities, a gender gap is evident among students and staff members like in TU Berlin, where only one-third of students are female (33–34 %) [7] and among professors it is only one-fifth (20–21 %) [8]. Addressing these issues demands motivating young people, and regardless the gender, to access technical careers, where the conception of broader educational actions at K-12 is of utmost importance.

In this direction, the research community is publishing various groundwork to promote STEM topics at the K-12 level. Examples include the development of code like in [9]–[12], doing mathematics [13], demonstrators with electronic components [14], [15], massive open online courses (MOOC) [16], and initiatives conducted by companies with curricular and extracurricular activities, as in [17]. These works illustrate the trading direction at universities and industry to increasingly promote STEM topics.

However, we remark that these tools are commonly produced in master's or bachelor's academic programs by students at technical universities. When properly articulating academic programs at universities, the students' work may be guided to develop technical platforms, about which instructors later design K-12 activities. Within this paper, we conceive a technical platform to monitor the vitality of trees and the design of hands-on activities for K-12 students using this technology. Based on this experience, we later elaborate on a methodology of general applicability for technical universities to promote STEM topics at K-12.

The paper's content is organized as follows. In Section II we summarize the most recent papers on promoting STEM topics at the K-12 as conducted by universities. In Section III we provide illustrative remarks on our experience with developing drone-based monitoring with students at the university. Then, in Section IV we elaborate on a teaching plan to design hands-on activities with students at the K-12 level. Finally, Section V concludes the paper.

II. Ties between technical universities and K-12

Numerous examples are coursing at universities exposing K-12 students to STEM topics. Various learning formats take place like summer camps [18]–[22], courses conducted at high schools [23] and also to train educators [24]. Other examples include outreach programs at university labs [25], guided circuits through labs facilities [26], hands-on activities in workshops [27], [28], virtual courses [28], and scientific fairs and research symposiums [26].

Not only teaching activities but also products are also developed to introduce K-12 students. This is the case of using 3D printer technologies to introduce cells in biology for K-12 children [29]. Other examples include the development of visual interfaces to teach cryptography algorithms like in [27], [30], and to send and receive memes using satellite technologies [31].

Reported studies develop various practices aiming to spark students' curiosity along topics of direct applicability. Some examples are coding for solving thought-provoking questions [18], the integration of algorithms for communication security [27], or using microscopes to look at tiny structures [28]. There are also examples with communication electronics to depict and measure parameters of waveforms used in radio communications [25]. Most recent practices also deal with the sensing layer in internet of things (IoT) applications [32].

Other hands-on activities perform practices using environmental, proximity, biomedical, tactile, or radio-frequency identification (RFID) sensors [32]. For instance, to develop the monitoring of temperature and humidity using micro-controllers like in [19], [20]. Examples also address sound propagation in labs like in [26] measuring its speed and introducing waveform analysis in the frequency domain [20]. More complex practices assemble robots [22] and develop algorithms and prototypes for robots to self-steer following an arbitrary path [20], [28]. Using robots, application developments also address looking for objects in a room [21], and manipulate light detection and ranging (LiDAR) images as captured by robots [23].

These initiatives are implemented with the direct enrollment of university staff members, both undergraduate and graduate students. Examples are in daily sessions with K-12 students, like in summer camps [18] and in scientific fears where K-12 students are the presenters and the staff is the audience [26]. In a similar format, undergraduate and graduate students play active roles as organizers [28] (including high-school students like in [22]), mentors [26], and developers of educational products for the K-12 level [31]. Other examples are with graduate students playing an active role as a presenter [25], or supervising [20] lab sessions. Besides, these topics are developed as programs and practices to conduct with K-12 students and for training high-school educators as well [19], [23], [32].

These examples in the literature illustrate the variety of approaches to developing STEM topics for the K-12 level at universities. These developments can be straightly positioned as tools to introduce STEM topics at the K-12 level. In this direction, we introduce an example of climate protection, aiming to generalize this as a methodology. We intend to elaborate on strategies to generalize the development of tools at technical universities and later introduce STEM topics at the K-12 level.

III. Previous experience at the University

As part of the curriculum at the technical university TU Berlin, Germany, we conduct the subject "Student Semester Projects" at the School of Electrical Engineering and Computer Science. This subject is a class for bachelor and master students typically comprising 6 credit points, i.e., a 150–180 h workload per semester. Each semester, several projects are conducted by students in small groups (typically 3–5 members) according to their preferences.

In this class, we developed two projects with students during the academic years 2021 and 2022. The project in 2021 was based on simulating the flight of a drone and the localization of CO_2 source of emissions. The second project in 2022 was developed using actual equipment, integrating a humidity sensor and a microcontroller into a drone. Both projects are conducted by supervising three student's work in the master course. Next sections provide further details on the two project's development.

A. *Simulating the drone flight*

During the academic year 2021, students developed in Matlab a drone flight simulator aiming to identify the source of CO_2 emissions. The students implemented the block diagram illustrated in Fig. 2 to connect the drone's flight with the monitoring operation. With this block diagram, students controlled drone flight missions with different paths like the circular one and also emulated the measurement of CO_2 emissions; see further details in [1].

In the monitoring block, students implemented the algorithm in Fig. 3 to localize the source of CO_2 emissions. The algorithm's conception is to fly the drone to read concentration levels of CO_2 levels in the surroundings and later estimate its position using Fick's 2nd law formula [34, Eq. (6)]; further details are given in [1]. With the monitoring block, students printed the readings of the CO_2 levels with time, and the estimated coordinates for the source of emissions.

1) The Educational Outcomes: This project allowed to develop technical skills with master students and plan for teaching activities at the K-12 levels. Master's students developed a measurement platform in software to fly a drone and localize the source of CO_2 emissions. Correspondingly, this required developing coding skills to integrate and operate the components and also analytic skills when solving the equations to localize the source.

Activities with K-12 students can be developed using the simulator to introduce natural sciences and technology topics related to climate surveillance. As for natural science, a teaching plan can introduce the physics of the diffusion process in open environments, the chemical formulation of CO_2 molecules, and the mathematics to formulate the localization algorithms. As regards technology, a teaching plan can be designed to introduce simulator components for sensors and drones, the development of code to fly a drone and acquire data, as well to localize the source of emissions. An example of such a teaching plan is accessible in [1].

B. *Flying the drone*

In the second project, as conducted during the academic year 2022, the students implemented a measurement platform with a drone in actual technology. The students integrated a humidity sensor with a microcontroller to later assemble those to a flying drone in remote connection with a PC; see Fig. 4. As depicted in this figure, students integrated wired and wireless connections (bluetooth) to emulate humidity data acquisition with the drone. The platform included a graphical interface to plot the readings of the humidity sensor with time.

Along the semester, the student fulfilled the following technical assignments:

- Implement the bluetooth connection of the Matlab simulator with the drone.
- Soldering the humidity sensor to the microcontroller board, see Fig. 5.
- Assemble the humidity sensor, microcontroller, battery, and drone.
- Implement the bluetooth connection between the Matlab interface in the PC and the microcontroller.
- Program the microcontroller to read the humidity sensor levels.
- Program the localization mechanism of the humidity source with the concentration level as provided by the sensor.

As for the project components, we acquired the listed items in Table I using funds from the award program Acceleration Contest, as promoted by the IEEE Region 8 [35]. The components comprise a humidity sensor, microcontroller, battery, and drone. The microcontroller reads the sensor data and sends the measurements to a PC via Bluetooth remote connection. The drone is controlled with Matlab running on a PC using a predefined flight mission. The battery was used to power the humidity sensor and the microcontroller, while both were integrated to the low cost Tello drone.

TABLE I: List of components and costs.

Item	Cost per unit (EUR)
Humidity Sensor: sid-Grove – I I2C	9.5
Battery: LP-503035 Lithium-Polymer / LiPo	6.5
Microcontroller: Adafruit ESP32 Feather V2	25
DJI Ryze Tello Drone	208
Total	249

The project was developed with the direct supervision of two staff members at the university. At the end of the project, the students presented their results with a life demo; see Fig. 6. We also discussed further steps to improve the solution and plan for other applications using the drone and the sensors. The supervisor also discussed with the students the intentions to later conduct activities at the K-12 level using this platform.

1) The Educational Outcomes: This project strengthened various educational outcomes for bachelor's and K-12 levels. Bachelor students assembled a measurement platform comprised of a flying drone and CO_2 meter and developed code to control it. Using the platform, activities with K-12 students can be developed to examine and appraise the main components of this platform and develop code (low complexity) to locate the source of CO_2 emissions. A detailed description of the learning outcomes is the following:

- At the bachelor level, students were able to: Assemble a hardware platform for the real-time measurement of CO_2

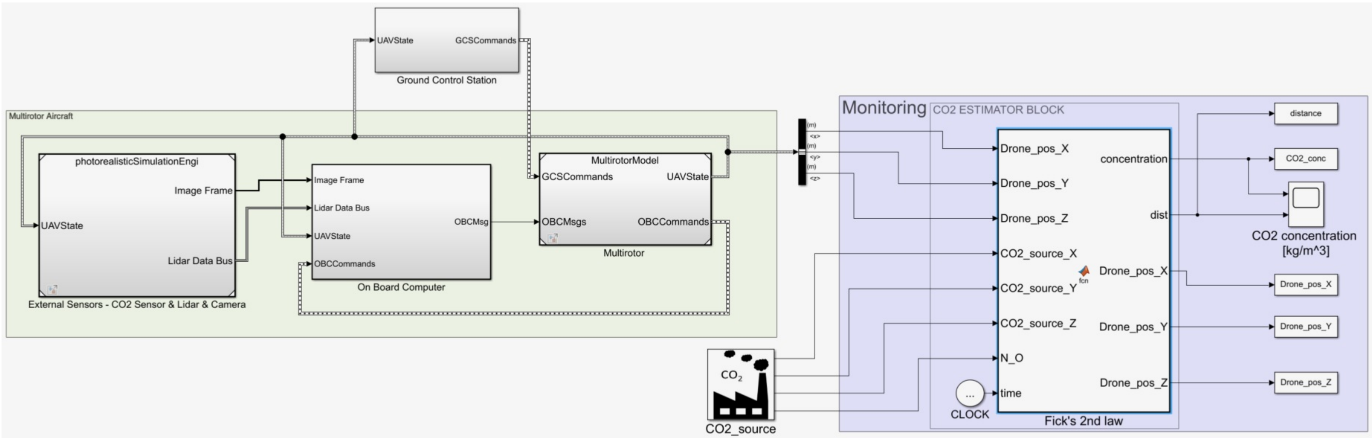

Fig. 2: Simulink design to control the drone path [33].

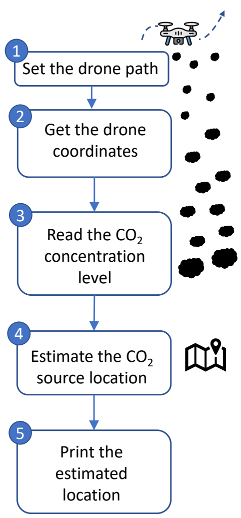

Fig. 3: Block diagram for the algorithm to localize the source of emissions [1].

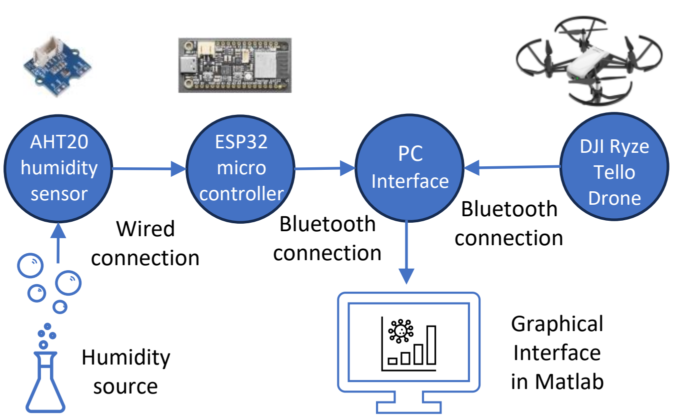

Fig. 4: Hardware platform for the reading of humidity levels.

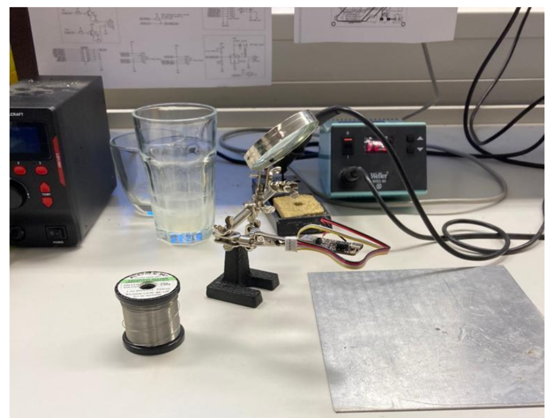

Fig. 5: Soldering station where the master's students integrated the microcontroller with the humidity sensor.

Fig. 6: Students are presenting the project and explaining the integration of the humidity sensor to the drone.

emissions in the atmosphere, develop code for the real-time operation of the platform, assemble the hardware connection between the CO_2 meter to the drone, and sketch the measurement of CO_2 levels in the atmosphere using the integrated meter.

- At the K-12 level, a teaching plan can be conducted for students to: Define the main blocks for hardware

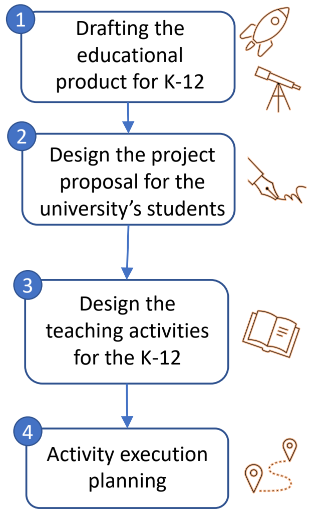

Fig. 7: Methodology steps to promote STEM at K-12.

and software components of the measurement platform, discuss the flow diagram of the measurement platform, Appraise the range of humidity levels, and to develop code to find the source of emissions.

IV. A Methodology to promote STEM at K-12

The two examples illustrated in the previous Section manifest direct means to plan for hands-on activities at the K-12 level. Our core constituent is pivoting on classes based on project-based learning methodologies. Educators can formulate a teaching plan for the K-12 level using the software and hardware platforms provided by the student's project completion.

Generalizing our previous experience, we formulate four steps methodology aiming to assist educators in promoting STEM's topics. We frame the methodology with an end-user (K-12 students) perspective, allowing us to design a teaching plan for the university curriculum and the K-12 level later. A summary of the methodology is depicted in Fig. 7 with the details as reading below

Step 1- Drafting the educational product for the K-12 level: Formulating project's outputs for university students is a regular task as the topic is typically part of ongoing university research. What becomes challenging is customizing the project outputs to the K-12 educational level. Developed software and hardware products should be quite automated to avoid the later complex development of educational activities with K-12 students. This eventually introduces more technical complexity for students at the university, as they need to produce a friendly interface.

In this regard, drafting the project output should consider a balance between the scientific component of the project and its technical complexity. The project's product should be elaborated enough to include a friendly graphical user interface or to develop illustrative use cases upon which teaching activities can be planned later. Furthermore, the project product should raise students' interest at the K-12 level.

The literature provides various products for the K-12 level that can be taken as inspiration; see Section II. Examples are robots that follow predefined paths [20], sensor networks for biomedical signals [32], communication transceivers for radio signals [25], or in our case, the maneuver of drones for the climate surveillance [1]. Many other practical examples are online accessible through the IEEE TRYEngineering portal in [36].

Step 2- Design the project proposal for the university's students: Once the project output is defined, a clear goal towards the product development can be phrased. The goal definition leads to state assignments that students at university should fulfill at a complex level that follows the academic program. As this project will develop a product as the main output, the assignments will be mostly located in the Creation and Evaluation stages of Bloom's taxonomy (see [37, Fig. 3.2]), referring to designing, assembling, or valuing software and hardware components.

Besides, we observed positive student satisfaction levels when explaining the intention to develop an educational product for the K-12 education level. Clearly stating the intended use of the project's output in the proposal will benefit the project execution. It will also allow students to socially engage in promoting STEM.

Step 3- Design the teaching activities for the K-12 educational level: The teaching plan should include three main components: the context, the fundamentals and the hands-on activities. As for the context the teaching activities should be planned to introduce the driving motivation for the topic at hand. For instance, monitoring of environmental variables [38] for climate protection, autonomous robots [39] for industrial applications, or electronic components allowing communications [40], are some examples accessible in the IEEE TRYEnginnering portal. This motivation should be the driving force that initially sparks students' curiosity. The fundamentals of the given product can be introduced on the main constituent blocks of the products and their operation as a system.[1]

Most importantly, the teaching plan should strive for hands-on activities, allowing students to implement and run solutions and feel in a pathway of discovery. These three components should be planned to the extent of the session, like in small formats such as demos, and workshops, or bigger formats such as summer camps or school teaching sessions; see some examples in Section II. It is also crucial to plan for the timeline and the balance between introducing context and fundamentals with hands-on activities, which we recommend should be the larger part.

Step 4- Activity execution planning: Planning requires defining the following components first: the date, place, program, and registration process. Secondly, defining the par-

[1]The fundamentals can also be introduced as part of the engineering design process, see the handout material in [41, Slide 14].

ticipant organizers and the availability of resources, see [41, Slide 22]. This will lead to specify a budget plan for expenses related to materials acquisition and, optionally, catering, space renting, and transportation.

Defining these components will be necessary to advertise the event later, which is crucial to guarantee the attendee levels. The advertising strategy can be created using basics for communicating concepts like defining the target audience and making a SWOT analysis to prepare a call later. The SWOT analysis defines the strengths, weaknesses, opportunities, and risks in terms of intended activity and participants. Having defined the intention to attract K-12 students, the target audience for the advertising material will be students, school educators, and parents. For instance, as a strength, there is a growing awareness of technology's impact on everyday life, and as a weakness, there is little knowledge of the capabilities and development of such technologies. In this way, we can produce content as a call when particularizing around the specific project's product defined in Step 1.

Secondly, defining the number of volunteers needed to run is crucial to implement the activity. Small formats like demos in fairs or short sessions with a small group of attendees will require one or two volunteers and bigger formats like summer camps or long session workshops might require more volunteers. The activity should be first highly coordinated among the volunteers. Discussing the lesson plan is mandatory in defining each role to guide the participant students' work.

V. Conclusion and Outlooks

This paper evidences the feasibility of promoting STEM leveraging technical universities' reach means and capacities. We illustrate with a climate protection topic a product conception developed by university students, which is later used to promote STEM at K-12. Generalizing this experience, we elaborate on the methodology that synergically intertwines educational practices at the university with planning teaching activities for the K-12 educational level. The methodology stems from a project-oriented class, where students must develop technical solutions, and the methodology gradually introduces the development of a teaching plan following four steps. In future work, we plan to elaborate further insights into the different steps of this methodology in a way that illustrate further the conception of teaching plans for the K-12 level.

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