Work in Progress: Bridging University Technical Innovations to K-12 Classrooms through Hands-on Activities in Plant Bioelectrics and AI

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***Abstract*—Technologies developed at universities are direct means to conceive a teaching plan for promoting science, technology, engineering and mathematics (STEM) at the K-12 level of education. This work-in-progress develops this notion: We elaborate a teaching plan for K-12 students based on technologies for recording plant bioelectrical activity. The teaching plan sketches hands-on activities, where pupils can self-assemble the electronic components such as the electro-potential sensor, analog-to-digital (ADC) converter, and Arduino board for processing, as designed by research students at Politecnico di Milano. Using our project as a blueprint, we aim to support other educators at universities to promote further STEM and expose pupils to technical developments at universities.**

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

I. Introduction

NEXT to its primary purpose, the diverse research and development at technical universities endow an additional benefit: projects are also as a source for developing novel educational activities at the K-12 level. Project-based learning courses and research thesis produce valuable content and tools that can be used to promote science, technology, engineering and mathematics (STEM). With the regular update of these projects, they could be transformed into valuable educational course material for preparing STEM-promoting activities later. In this work, we combine our previously reported methodology for developing K-12 courses in [1] by using a recent real-world course for plant-bioelectric monitoring technology in [2]. This can serve as a blueprint for other educators, already related to a similar technology in universities' classrooms, to generate K-12 teaching material.

The methodology we proposed first in [1] consists of four steps: The first step sketches the educational product for the K-12 level. Examples in the literature include software interfaces for teaching coding [3] or hardware components for teaching electronics, as in [4]. The second step is to develop the design of the teaching activities at the technical university. This should be developed at a project-based class, see e.g. [5], or through the supervision of theses. The third step comprises designing the teaching activities for the K-12 level, where theoretical fundamentals and hands-on activities need to be mixed. Finally, the last step includes the activity execution planning accounting for the specifics of the event with the K-12 pupils: place, dates, sessions, etc. Published examples count for events format in workshop sessions as in [3] or in after-school program activities as in [6].

In this work-in-progress paper, we use the plant-bioelectric monitoring technology as an example for developing a corresponding K-12 course. The target group of this project are K-12 pupils to introduce them to biology as well as computer science. We also introduce the basics of artificial intelligence (AI) to account for this recent developments in the field and raise further interest to participate in the course.

As the first step of the methodology is already defined by the topic of plant bioelectric monitoring, we primarily focus on the second and third steps of the methodology, described in Sections II and III, respectively: In the second step, we use electronic equipment and AI to predict plant water stress conditions. This enables us to create a teaching plan in the methodology's third step, which will be realized in seminars and lab sessions. Section IV will describe our initial experiences presenting the plant-bioelectric monitoring technology to the general public.

II. The Technology developed at Universities

To demonstrate how technology developed at universities can be used to create K-12 courses, we use a biosensor setup for measuring the bioelectrical activities of plants that was made by research students at Politecnico di Milano. The biosensor is installed on a GrowBox of size $120\,\mathrm{cm} \times 120\,\mathrm{cm} \times 200\,\mathrm{cm}$, providing ample space for multiple plants, sensors, and equipment, see Fig. 1. The components of this real-world example are as follows:

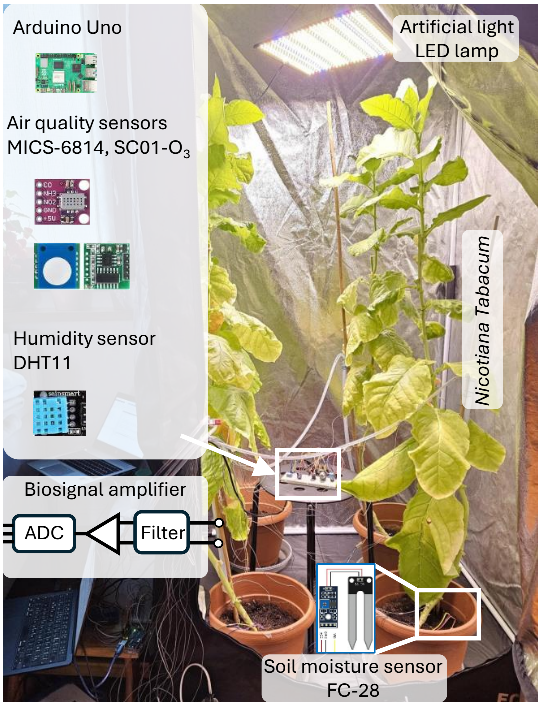

Fig. 1: GrowBox system with integrated environmental sensors, actuators, lighting module, and irrigation system [2].

1) Biological components: Nicotiana tabacum is used for its strong electrophysiological responses, suitable for studying plant action potentials [2]. Plants are grown in $25\,\mathrm{cm}$ diameter plastic pots with $27\,\mathrm{cm}$ saucers. The substrate consists of a $10\,\mathrm{L}$ layer of $9-20\,\mathrm{mm}$ clay for drainage, topped with potting soil and little amount of NPK fertilizer, ensuring optimal root health and nutrient availability.

2) Lighting Module: LED panels provide a full light spectrum essential for all growth stages [7]. The $40\,\mathrm{W}$ LED panels emit a balanced mix of blue ($450\,\mathrm{nm}$), red ($660\,\mathrm{nm}$), and warm white ($3500\,\mathrm{K}$) light, ideal for plant development [7]. The panel's height and lighting schedules are adjusted to each growth stage and controlled by an automated timer to simulate day-night cycles.

3) Irrigation Module: Automated irrigation is managed by peristaltic pumps connected to each plant pot. The pumps are controlled through a $5\,\mathrm{V}$ relay to maintain the soil moisture in the range $75-80\,\%$, which optimizes stomatal conductance and photosynthesis [8]. Capacitive soil moisture sensors are calibrated by establishing dry ($0\,\%$) and wet ($0\,\%$) reference points through air and water exposure, respectively. After calibration, sensors correlate soil moisture with humidity percentages, setting a threshold of 75% to maintain moisture between $75\,\%$ and $80\,\%$ [8].

4) Data Acquisition System: The sensor array includes a capacitive soil moisture sensor FC-28, a gas sensor MICS-6814 for CO, NH_3, and NO_2 levels, a light UV sensor, an SC01-O_3 sensor for Ozone measurements, and a DHT11 sensor for temperature and humidity. Sensor data is logged each $30\,\mathrm{min}$, enabling continuous monitoring and historical analysis of irrigation events to optimize plant health and productivity. Besides, the plants' electric potential (EP) is acquired using the Vivent biosignal amplifier [9] with eight dual-electrode pairs (LEAF and GND) to minimize noise and enhance signal quality [10]. The signal is digitized with the analog-to-digital (ADC) converter in the Arduino board and stored on a Raspberry Pi processor for real-time analysis and experiment adjustments.

5) AI Data Processing: The raw EP signal is preprocessed by filtering in the frequency domain to remove noise; see details in [2, Sec. III B]. Subsequently, key features from the preprocessed signal are extracted, which will be used for classification, including statistical measures like mean, standard deviation, peak amplitudes, and signal variance, see [2, Sec. III B.]. These extracted features are then input into supervised machine learning models selected for efficacy and simplicity, such as Support Vector Machine (SVM) or Random Forest. Finally, we apply a binary classification approach to distinguish between two clearly defined stress exposure classes: light and dark. This workflow involves data collection, pre-processing, feature selection, and classification using a chosen algorithm.

III. Sketching a Teaching Plan for the K-12 level

The technological framework described provides plenty of theoretical and practical aspects. At the K-12 level, STEM can be promoted using this setup to introduce pupils to the biology of plants, electronics, hardware, and AI. Lab sessions can be organized to introduce theoretical aspects of biology, electronics, and AI. Hands-on activities can be planned to assemble the setup, interact with the software component while coding, or do simple AI tasks such as using a pre-trained model on novel data and analyzing its results. To illustrate a plan for the K-12 level, the teaching topics can follow these subjects for the theoretical sessions:

1) Introduction to plant biology: Pupils can be exposed to the physiology and biochemistry of plants to describe their adaptive response to various stressors, such as lack of water, light, nutrients, or the attack of pathogen attacks. The plan can include the propagation of electric signals throughout plants, including amplitude levels, distance range, and physical medium; see [11, Box 1]. Topics can also include the response of plants to environmental stimuli through action potentials, variation potentials, and system potentials; see [11, Table 1].

2) Introduction to biosensor technologies: Here, topics can span from a holistic view of technologies in agriculture to specifics of sensor functioning and their interfaces. The topic lends perse to introduce content related to sustainable farming practices supported by AI, see [12], or the impact of global environmental factors on plants, see [13]. Relying on the technical components described in the above section, more teaching content can cover the operating principles of biosensors and data acquisition systems with the integration of ADCs, digital displays, and microprocessor boards. Hands-on activities can be prepared through the following actions:

3) Assembly of the technological setup: Pupils can be guided to interconnect the components described in the above section. Along with this activity, the instructor can introduce the various units and interfaces and their electric levels and formats. More advanced activities can be planned to implement complex topologies, such as bus connections, and increase the number of sensors to cover crops' larger areas.

4) AI modules integration: Activities can be prepared to integrate pre-trained AI modules for classifying the biosensor recorded sequence. For instance, pupils can be exposed to basic templates in Matlab code, where classification modules such as Random Forest and SVM are connected with inputs, and their outputs are visualized in plots. This visualization can also be interpreted in light of stress indicators and the physiology of the plants. Further activities can be prepared by training these AI methods and tuning their hyperparameters, such as the number of leaves for the Random Forest or the kernel type for the SVM module. Advanced sessions can be planned by introducing more complex AI methodologies like Reinforcement Learning (RL), allowing the control of light and water irrigation levels in response to the bioelectric activity of the plants. Another avenue would be to introduce the concept of explainable AI to pupils; multiple methods exists for time series acquired from humans [14] that could be easily transferred to the plant signals. Therefore, course participants could also gain insights into the reasoning behind the models.

IV. Early Experiences

We already have experience with the GrowBox in events with the general public. A simplified version of the GrowBox was showcased during the Milano Green Week in September 2024.[1] This interactive workshop highlighted how plants' electrical signals and sensors can monitor urban pollution while promoting well-being and sustainability. Twenty participants completed a survey, giving their perceptions of the educational impact of this product.

The survey revealed that only $5\,\%$ of participants already knew phytosensors. This indicates a significant opportunity to increase awareness through interactive workshops and demonstrations. Regarding interest, $40\,\%$ of respondents expressed being "quite interested," and $30\,\%$ were "very interested" in the concept of using plants to monitor urban pollution. This high level of interest underscores the potential of photosensors to engage the public in environmental monitoring and STEM education. When asked about active participation, $60\,\%$ of respondents were willing to participate in pilot projects using photosensors, highlighting a strong community interest in collaborative environmental initiatives.

The workshop effectively demonstrated the integration of biology and computer science through hands-on activities. Participants gained a foundational understanding of plant bioelectrical activities and their application in environmental monitoring. The workshop's interactive nature also fostered curiosity and enthusiasm toward STEM subjects, particularly in real-world environmental challenges.

[1]See details of this event in https://www.comune.milano.it/en/aree-tematiche/verde/milano-green-week-2024

V. Conclusion and Outlooks

The developments of educational products for the K-12 level can be more natural than expected. Project-based classes at technical universities built products that can be later used to introduce concepts and plan for hands-on activities. This work in progress illustrates this straightforward connection with teaching activities grounded in product technologies developed by student researchers at Politecnico de Milano. We plan for future work to follow through on-site activities at the K-12 levels and elaborate more teaching activities.

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