STEMx - Extreme Multidisciplinarity for Programming, Mathematics, Physics, and Biology Interwoven into One Agricultural Educational Project

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STEMx - Екстремна мултидисциплинарност за програмиране, математика, физика и биология, вплетени в един земеделски образователен проект

Abstract

Multidisciplinarity is at the core of the STEM approach to learning science, technology, engineering, and mathematics, but this is still misinterpreted, and as a result, different subjects are still taught separately. Mixing them all together presents many challenges to educators. While working on a school agricultural project, many of those challenges were identified and analyzed, and solutions were sought. STEMx, where the "x" stands for extreme multidisciplinarity, implies that all the subjects involved in the educational project must be taught together within the same class, allowing the acquisition of the necessary knowledge and skills while establishing the connection between different sciences using them for solving practical everyday problems. The agricultural project that is used is an automated water drip irrigation unit that takes care of one plant.

Keywords: *STEM; Multidisciplinary; Agriculture; Curriculum.*

Introduction

Multidisciplinarity is at the core of the STEM approach to learning science, technology, engineering, and mathematics, but this is still misinterpreted. As a result, different subjects are simply grouped rather than integrated. This leads to teaching each subject in isolation, with little or no cross-disciplinary connections, thus failing to fully leverage the potential of the STEM approach, which is meant to help students see the links between disciplines.

While working on a school STEM project called AWDIU (Automated Water Drip Irrigation Unit) for automated irrigation of one plant, some of the related issues were explored and analyzed. This led to the development of an extremely integrated STEM curriculum that we called STEMx, where "x" stands for "extreme".

Exposition

As global economies increasingly rely on advanced technologies, countries investing in STEM education will have a competitive edge. The workforce in these countries will be better equipped to take on high-value, high-skill jobs and contribute to the growth of the tech-driven economy [1].

A report by McKinsey links innovation in STEM fields to economic growth. As industries evolve and develop new technologies, the workforce must be capable of driving this innovation.

STEM education nurtures creativity, problem-solving, and technical expertise, crucial to developing and leveraging new technologies that will power future industries [2].

Problems

Creating multidisciplinary educational content is not a trivial task and poses many challenges to the educational environment. Let's outline some of them and then focus on the solution to just a few of them.

1. The number one challenge is the **curriculum** design. Developing a curriculum that seamlessly integrates different school disciplines requires careful planning and a deep understanding of how these subjects intersect. Authors need to design lessons and projects that draw on multiple subjects, which can be complex and time-consuming.

2. The lack of teaching **expertise** in multiple subjects is the second common challenge. Most educators are specialized in one discipline, which makes it difficult to teach in an integrated manner.

3. **Assessment** is another obstacle. Traditional methods focus on individual subjects rather than on integrated skills and knowledge, making it difficult to design assessments that measure interdisciplinary knowledge.

4. Extreme multidisciplinary STEM requires special **products**, such as hands-on engineering projects or specific materials that might not readily be available in school.

5. The institutional **structure** in most educational environments is organized around specific subjects, including the scheduling, and does not easily accommodate interdisciplinary teaching.

Addressing these challenges requires a **change** in both **mindset** and **practice**. Professional development for teachers should emphasize cross-disciplinary teaching and collaborative curriculum planning.

Integrating **project-based learning**, where students work on real-world problems that require the application of multiple STEM disciplines, can make the multidisciplinary approach easily achievable.

Approach

We designed an agriculture STEM project for the automated irrigation of one plant to solve some of the challenges of STEMx - the extremely integrated STEM curriculum. We called it AWDIU, which stands for an Automated Water Drip Irrigation Unit.

Is this new?

Creating an automated irrigation system as a learning tool in the context of STEM is not new. There are many developments in this direction, which set various goals and achieve different results.

There are some that are rather primitive [3], and although they achieve the goal of watering the plant, they do not provide tools and learning materials to acquire a sufficient amount of new knowledge.

On the far end, there is research and work where the system is overly complicated and not very suitable for younger learners. For example, they use cameras to determine the environmental parameters by their appearance [4] or utilize IoT (Internet of Things) to communicate with external systems wirelessly [5].

Our Goal

Our goal with the AWDIU project is to develop an intelligent system that automates the process of watering a plant by integrating technologies such as sensors, data analytics, and automated control. More importantly, it is an educational tool to integrate science, technology, engineering, and mathematics concepts into a hands-on learning experience, providing foundational knowledge to learners in the respective STEM fields.

The project is also a great way to demonstrate the real-world applications of science, technology, engineering, and mathematics, helping students understand how these disciplines work together in problem-solving and innovation.

Target Grade Level

The **AWDIU** project is suitable for students in a very wide age and grade range because the practical skills required to complete it are within their capabilities.

The knowledge required for the project could be aligned with the curriculum standards for that grade in the following subjects: programming, mathematics, physics, and biology [6], [7].

For example, in the science curriculum, students would be expected to understand the basic principles of electricity, which are directly applied in the project's modules, such as temperature, light, and soil moisture measurement.

During the development of the AWDIU project, we worked with students **from grade 4 to grade 6**.

System Components

The system consists of the following sub-modules:

- Microcontroller module for controlling all the systems.
- Sensor for temperature measurement.
- Sensor for light measurement.
- Sensor for moisture measurement.
- Motor driver module.
- Water pump system, including water pump, pipes, and water valve.
- Water intake system, including water filter, pipes, and funnel.
- Plant in a pot with soil.
- Water container, including level probe.
- Wood frame construction for the project.

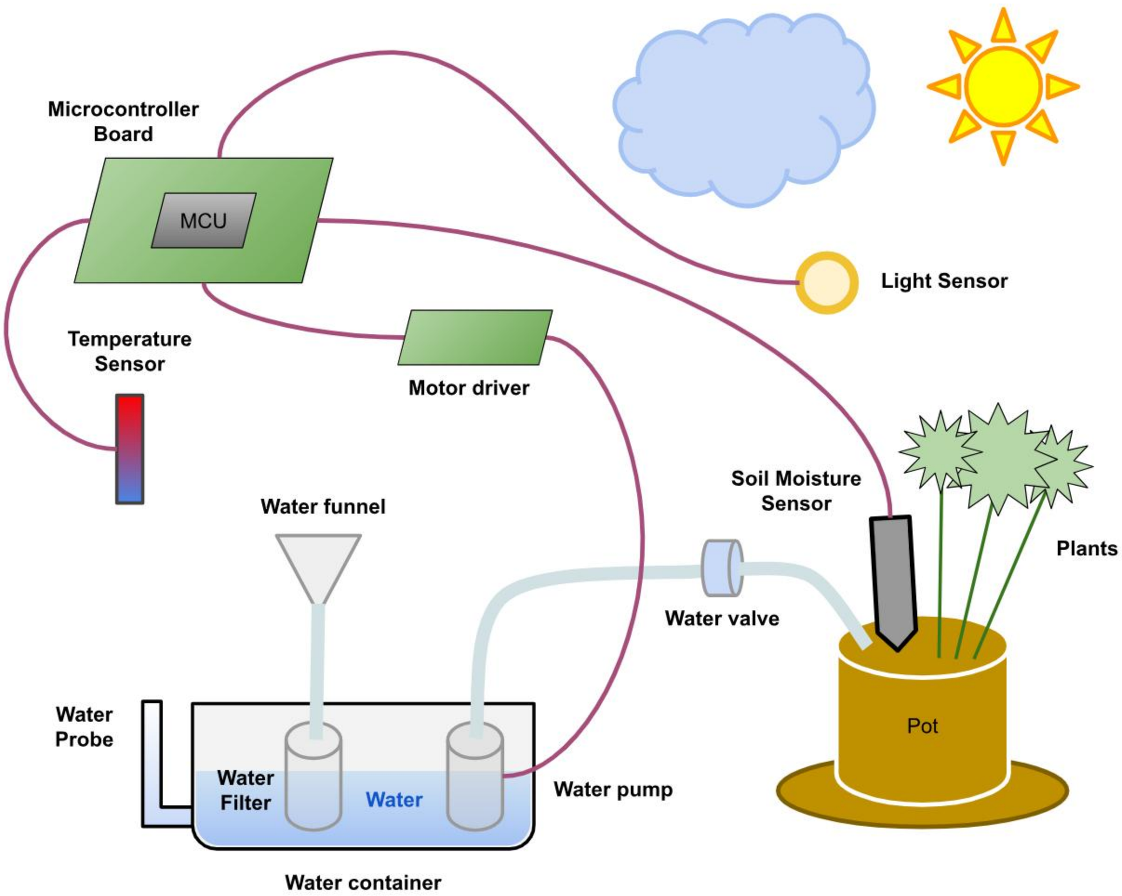

Fig. 1. System Diagram

Challenges

Before diving into the details of the project, let's see how it corresponds with the 5 challenges outlined above.

1. Curriculum Design

The automated irrigation project easily integrates science, technology, engineering, and mathematics. Students learn about plant biology, soil science, and the water needs of different plants. The project involves programming microcontrollers, using sensors, and controlling actuators to automate the irrigation process. Students design and build a prototype of their irrigation system, including selecting materials and prototyping. They calculate the optimal water flow, analyze sensor data, and use algorithms to determine watering schedules based on light and temperature.

2. Teacher Expertise

This project allows teachers from different disciplines to collaborate using their expertise. A science teacher might help students understand plant needs, while a technology teacher could assist with the programming aspect. This collaboration can also serve as professional development, helping teachers gain confidence in areas outside their primary discipline.

3. Assessment

The project allows for a variety of assessment methods: (1) Checking student's understanding as they design and build the system; (2) Evaluating the final project, including the functionality of the irrigation system and the student's ability to explain the science behind their decisions; (3) Students can present their projects to the class, allowing for peer feedback and collaborative learning.

4. Resource Availability

Access to specialized resources could be a challenge, but the depth of detail in which this project is covered here can be very helpful. Also, a focused project like this one may require fewer specialized materials than broader, less defined multidisciplinary activities.

Schools can also seek partnerships with local agricultural businesses or community organizations to obtain the necessary tools and materials.

5. Institutional Structure

This project can be structured to fit into existing school timetables by dividing the tasks between different classes (e.g., plant biology science, data analysis mathematics, programming technology).

Alternatively, schools can implement project-based learning periods that allow for interdisciplinary collaboration.

Methodological Framework

The outlined challenges can only be solved with a proper methodological framework. Over the course of the past several years, we developed such a methodology, and it is now an integral part of the overall mix of product, content, and education.

Problem-Knowledge-Solution Teaching Methodology

This method consists of mini iterations of the type **Problem-Knowledge-Solution** (**PKS**), which means the following:

1. First, we present a practical problem that needs to be solved;
2. Then, we provide the knowledge necessary to solve this problem;

Let's pause here briefly: presenting the problem first gives students perspective on why they need the knowledge they will acquire in the next step. This approach to presenting the problem plays an extremely important role in increasing students' motivation.

3. Together with the students, we reach the solution to the problem with the help of the knowledge just acquired.

The moment of finding the solution is extremely satisfying for the students and provides additional motivation during the learning process.

These mini **PKS** iterations are relatively short - ranging from 5 to 15 minutes, with no more than 3-4 iterations in a single lesson. Of course, this depends on the complexity of the problem and the student's preparation.

It is important to note that the problems presented should not be highly complex and should focus on the specific knowledge to be acquired.

This methodology has been tested in several schools and has been regularly used for a fourth year as part of the regular classes.

The Problem-Knowledge-Solution teaching methodology is the subject of my previous "Multidisciplinary methodology in regular classes using a physical STEM product" report [8].

Modules and Activities

Let's review each component of the system, outline its function, identify the corresponding activities and knowledge, and see how it relates to the **STEMx** concept.

Microcontroller Board

This is a microcontroller board based on the ATtiny85 microcontroller by Microchip. It is used to get the values of sensors, to control the pump and other modules. An additional board is also part of this module that is used to connect the microcontroller to the other components.

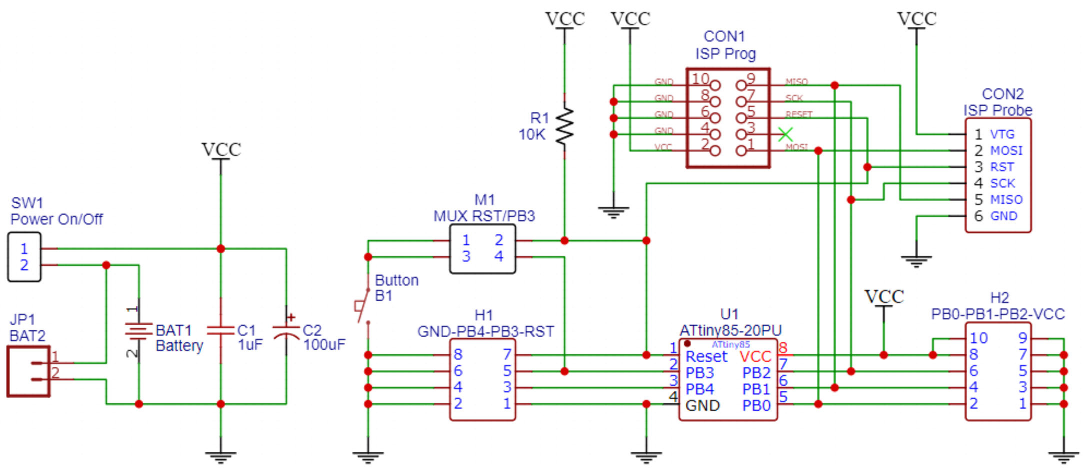

Fig. 2. Microcontroller System Schematics

Activities

Students must assemble the electronic boards by soldering all the electronic components onto the circuit board. They learn how to use a soldering iron, which is an important skill in electronics and engineering.

Soldering requires careful **attention** to detail, as students must make sure that connections are secure and electronic parts are properly placed on the board. They also learn important **safety protocols** associated with handling soldering irons and working with electronics.

If something doesn't work as expected, students could engage in troubleshooting, learning to diagnose issues, test components, and correct mistakes.

Knowledge

While students work with resistors, capacitors, and other electronic components, they learn to identify these parts and understand their functions within a circuit.

By physically placing and connecting these components, students gain insights into how each part contributes to the overall operation of the microcontroller system. Understanding how these components interact with the microcontroller deepens their comprehension of how input and output processes are managed in such systems.

Students might need to apply **Ohm's Law** to determine the appropriate resistor values for their circuits, learning about the relationship between voltage, current, and resistance. **Kirchhoff's Laws** are also applicable, especially in the more complex circuits.

STEMx: Students are required to use new knowledge from physics, engineering, technology, programming, and mathematics - all at the same time.

Temperature measurement

To measure the ambient temperature of the environment we use the microcontroller's built-in temperature sensor. The microcontroller's ADC (Analog-to-Digital Convertor) provides a digital value between 0 and 1023 that corresponds to the analog voltage from the temperature sensor. To interpret this digital value as a temperature in degrees Celsius, students need to map it correctly.

STEMx: Understanding sensor data interpretation; Mathematical mapping and calibration; Microcontroller programming; Practical applications; Problem-solving skills and error handling.

Light measurement

To measure the light of the environment, we use a photoresistor and a regular resistor connected as a voltage divider whose middle point is connected to one of the microcontroller's ADC inputs.

STEMx: Understanding electronic components; Circuit design and analysis; Analog-to-digital conversion; Programming and algorithm development; Practical applications and system integration.

Moisture measurement

To measure the moisture of the soil, we use a module that has a capacitive sensing circuit. It uses the fact that soil has a higher capacity or higher inductance to the high-frequency electric signal applied to its probes.

This module is connected to one of the microcontroller's ADC inputs.

STEMx: Understanding capacitance and sensor technology; Circuit design and signal processing; Analog-to-digital conversion and data processing; Calibration and accuracy; Practical applications in agriculture; Problem-solving and system integration.

Motor driver

To switch on and off the water pump, we use a driver circuit that receives as input a digital signal from the microcontroller board and as output a switching MOSFET transistor that supplies power to the pump's motor.

STEMx: Understanding power electronics; Circuit design and integration; Power management and efficiency; Practical skills and troubleshooting; Safety and protection; Application in automation.

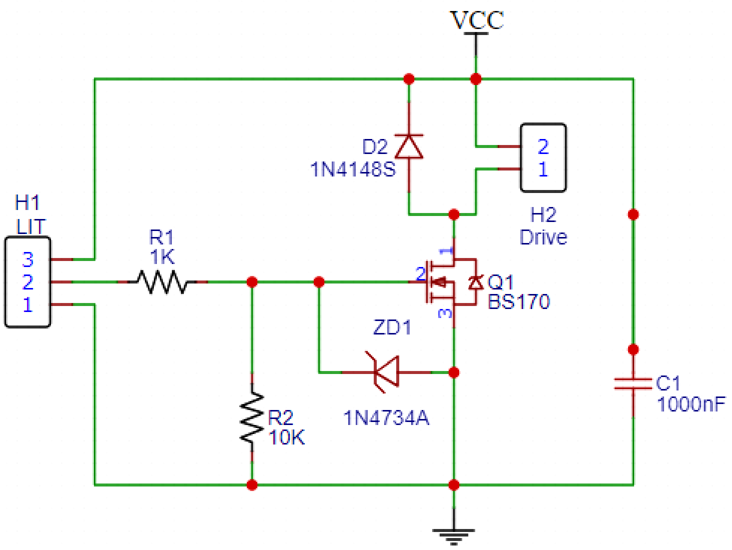

Fig. 3. Motor Driver Schematics

Water pump module

The water pump module includes:

- Water pump: for moving water from a reservoir to the plant, controlled by the microcontroller.
- Water lines (pipes): to carry the water from the reservoir to the pot.
- Water valve; to ensure that water only flows in one direction - from the reservoir through the water lines to the plant. It prevents the water from flowing back into the reservoir when the pump is turned off.

The water pump module teaches students about fluid dynamics, engineering design, and automation through a hands-on, practical approach. By working with the principles of communicating vessels and the mechanics of water distribution, students learn key physics concepts and how to apply them in real-world contexts.

STEMx: Physics fluid dynamics and pressure; Engineering design and optimization; Automation and control Systems; Sustainability and resource management.

Water intake module

The water intake module includes:

- Water lines (pipes): transport water from the external source (like a tap or a larger water tank) to the reservoir. They connect the funnel and the water filter to the reservoir, ensuring a steady flow of water into the system.
- Water filter: Removes impurities and particulates from the water before it enters the reservoir, preventing clogs.
- Funnel: To direct water from a larger opening into the narrower pipes of the system.

STEMx: Fluid dynamics and pressure management; System design and integration; Practical skills and application; Sustainability and resource management.

Plant and Pot

We use a small pot with soil and a basil plant. The mixture of the soil depends on the plant.

The basil plant serves as the living element in the AWDIU project, representing the biological system that requires specific environmental conditions, including moisture, light, and nutrients, to grow. The system is designed to maintain these conditions through automated irrigation.

The soil mixture should be tailored to the basil plant, providing the necessary nutrients, aeration, and moisture retention properties. The specific composition of the soil affects how water is absorbed and retained, and influences the irrigation schedule.

STEMx: Soil composition; Plant physiology and environmental control; System design and optimization; Sustainability and agricultural practices; Biology and engineering; Chemistry and soil science.

Water container

The water container serves as a reservoir to store water for an extended period. It ensures that there is a steady supply of water available for the irrigation system, reducing the need for frequent refilling and enabling the system to operate autonomously for longer periods.

The level probe is used to visually check and monitor the water level within the container, allowing users to ensure the system has enough water to function without interruption.

Getting an algae bloom on the water tank's inner surface could be prevented by spraying the outer surface with black paint.

This is an effective and educational approach that integrates biology, material science, and system maintenance.

STEMx: Water storage and management; Sensor technology and monitoring; System reliability and maintenance; Sustainability and conservation; Engineering and environmental science.

Wood frame

Wood frame construction for the AWDIU project adds a structural and design element that enhances the overall learning experience. Wood frame construction provides a stable and customizable platform for mounting the various components of the system, such as the water tank, sensors, and control electronics.

STEMx: This aspect of the project introduces students to basic principles of construction, material science, and design, practical skills in building and assembling structures.

Mathematics and Programming Component

In addition to the technical and electronic components, the project also incorporates important mathematical principles. For example, students apply formulas to calibrate sensors and analyze data collected from the system. They use basic arithmetic and algebra to calculate parameters such as temperature ranges, soil moisture levels, and water usage, allowing them to optimize the irrigation system.

Data Analysis

Students are responsible for interpreting the data collected from the temperature, soil moisture, and light sensors. This process involves mathematical analysis, such as calculating average values, identifying trends, and performing simple statistical analysis to determine the most effective watering schedule based on environmental conditions.

Use of Binary Search Algorithms

We use a **binary search algorithm** [9] to calibrate the soil moisture sensor and adjust its reading until it reaches the desired **calibration point**. The calibration starts with a predefined range of 0% to 100% moisture levels. We find the appropriate sensor calibration by repeatedly dividing the range in half and comparing the sensor reading to a target value.

The LED provides a visual indicator during this process, turning on when the sensor is correctly calibrated. This method ensures high precision in sensor calibration and minimizes the number of iterations required.

Similarly, we can calibrate the temperature and the light sensors.

How it works

The system employs a simple threshold-based algorithm to determine when to activate the irrigation system.

By default, the microcontroller is in a slipping state. At a certain period (that is determined experimentally) the microcontroller wakes up and performs its tasks. The microcontroller takes

3 measurements: Ambient temperature; Light intensity; and Soil moisture. Based on those 3 parameters, an algorithm should decide whether or not to water the plant.

This depends on various conditions and requirements. Here are just a few of them:

- Certain plants require a specific schedule for watering - could be more often or more seldom.
- Some plants require water during the cooler parts of the day - early morning and late in the evening.
- Some plants need a lot of water and very moist soil while others may require a dry environment.

Fig. 3. System Photograph

Determining the hour of the day

An interesting and challenging task is to determine the hour of the day, as this is one of the criteria for properly watering the plant. Since there is no real-time clock circuit on our microcontroller board, we must use other ways to approximately "guess" what part of the day is.

We use temperature and light measurements to collect data for a period of time, let's say the past 24 hours, and based on that, we do some simple statistical analysis to determine when it is day and when it is night. The criteria could be low light and low temperature for the night and high temperature and high light for the day. It is possible to have irregular spikes and drops of the values during the days and the nights, but a smarter algorithm should take that into account.

Data Collection and Analysis

It is not possible to create the perfect algorithm at the very beginning. That's why we need to make observations on how the plant is doing, collect data, analyze it, and make adjustments to the algorithm.

Further Optimization

The project provides numerous opportunities for optimization. From a technical perspective, improvements could be made to sensor calibration algorithms, enabling more precise readings or introducing additional sensors to monitor soil health and water quality.

In terms of data analysis, students could explore more advanced techniques, such as machine learning, to predict irrigation needs based on historical data. Additionally, the integration of weather data or more sophisticated watering schedules could optimize water usage.

Teachers and Students Roles

Collaboration between teachers and students in this process is crucial for positive outcomes. The **AWDIU** project, in conjunction with the **PKS** methodology approach, provides a great set of tools to do that.

Teachers serve as facilitators, guiding students through troubleshooting and optimization challenges. They introduce new concepts, support students in experimenting with changes, and provide constructive feedback to help students refine their work.

Students actively contribute by experimenting with the system's components, proposing optimizations, and collaborating with peers to improve the project. They engage in a process of trial and error, reflection, and iteration to enhance the project's technical and educational aspects.

Outcomes

While working on the **AWDIU** project using the **STEMx** approach, we created a new curriculum that is a forward-thinking, interdisciplinary program that prepares students for the complexities of the modern world.

It integrates multiple disciplines into a cohesive learning experience that enhances students' technical and critical thinking skills. It also instills a sense of responsibility and innovation that will be essential for tackling the challenges of their future jobs.

Conclusion

The **AWDIU** project is a good example of **STEMx**, illustrating how extreme multidisciplinarity can be harnessed to create a rich, engaging, and effective learning experience. By integrating science, technology, engineering, mathematics, and biology into a single project, the AWDIU not only addresses many of the challenges of implementing an integrated STEM curriculum but also prepares students for the complexities of real-world problem-solving. This project demonstrates how a well-designed STEMx initiative can transform education, providing students with the skills, knowledge, and experience they need to succeed in a rapidly changing world.

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