Toward the Digital Twin Education: Arduino Microcontroller Training for STEM Educators

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Abstract

The use of microcontrollers and programming have become essential nowadays. The introduction of coding early in students' academic experience is becoming the norm. However, teachers are not usually equipped with the knowledge of programming and very few of them use their skills to incorporate programming into their curriculum.

The University of North Texas organized a workshop for high, middle, and elementary school educators during the summer 2022. As a part of the workshop, lectures and practical examples were presented about the use of Arduino UNO board and sensor kit. In addition to simple, introductory applications of the board and basic programming, a code controlling temperature and humidity for a simulated nuclear power plan was provided. The UNO board was inserted into a 3D printed model of power plant, which was provided to each one of the teachers participating the workshop. Then, teachers implemented these modular lessons into their curriculum, reaching out a diverse student population in North Texas at various grade levels at their institutions.

1. Introduction

The digital twin concept has becoming more prominent in the later few years, especially in the field of industry 4.0, but it has been applied also to other industry fields such as healthcare and construction [1-3]. The concept expresses the blending of virtual and real worlds to predict systems behaviors based on data driven virtual products and verification [1], [4]. Programming is an important part of the digital twin concept [5].

In fact, programming has becoming more relevant in our lives as we live in an immersive digital age and is often associated to algorithmic thinking, which is not only a skill related to computers but becomes something more general that can be applied to other fields [6], [7].

Often, the class curriculum stays behind, despite different initiatives are suggested for implementation such as the USA initiative called Computer Science for All [6]. Moreover, some teachers are often biased about the difficulty of programming, which put barriers in their learning and subsequent transfer to the classroom [8].

Programming is also intimately connected to algorithm thinking; therefore, the importance of teaching programming is not only connected to computer skills but also focusing on solving real life problems by using logical models and implementing solutions applied to any other field [7].

Two different types of programming can be found named text-based and block-based. Block-based programming was proven to be more successful for students in younger age perhaps because associate often to robotics [6].

Programming associated with robotics curriculum and have mainly two ways to be introduced: as a learning object, and as a learning tool applied to other disciplines [9]. Teachers, especially with limited experience can be reluctant to introduce programming without proper training and they would require support from the school and technical support that often don't have due to the limited resource [9].

The use of Arduino and 3D printing has been proven effective in young students (K-12) it is useful to develop the skills needed to function well in a technology society and into different STEM fields [10-13].

In this paper, we introduced to STEM educators programming using Arduino UNO, Sensor Kit board, and developed an application for a nuclear power plan automated system. The educators were provided with lecture material, hardware, and discussed planning to embed programming into their curricula.

2. Workshop Content

The proposed workshop was designed for educators to eventually facilitate training of students in North Texas and introduce them basics of nuclear power, associated energy conversion process, instrumentation, and control aspects. The workshop title was "Introduction to Nuclear Power: Energy Conversion, Instrumentation, and Control," and it was hosted at the University of North Texas (UNT) Department of Mechanical Engineering during a selected day of summer 2022. Twelve educators attended the workshop, from elementary, middle, and high schools.

After the morning session introducing fundamentals of nuclear engineering and instrumentation, the afternoon session was dedicated to microcontroller, sensor integration, and programming. In this session, basic introduction of microcontrollers, Arduino UNO, and text-based program language were provided to the participants.

```
#define LED 6

void setup() {
  // put your setup code here, to run once:
  pinMode(LED,OUTPUT);     //Sets the pinMode to Output
}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(LED, HIGH); //Sets the voltage to high
  delay(1000);                              //Waits for 1000 milliseconds
  digitalWrite(LED, LOW);  //Sets the voltage to low
  delay(1000);             //Waits for 1000 milliseconds
}
```

Fig. 1. LED sample programming [16].

The sessions started illustrating what is a microcontroller and giving examples of applications such as traffic lights, nuclear power plants, industrial robots, and autonomous vehicles. Then, to continue to spark the interest of the educators, a discussion about the economic condition affected by the chip shortage. As chips are basic components for mobile phones, computers, and automotive nowadays, they are becoming essential components [14]. Due to the recent worldwide pandemic, the industrial supply chain has been disrupted causing and imbalance between offer and demand and having important repercussion on the economy [15].

The session was divided into two parts: i) programming, and ii) hardware and hands on implementation. During the first part, sample programs showing how each single elements of the sensor kit board were provided (e.g. the use of the led, the potentiometer, the light sensor, the barometer sensor, and the sound sensor). These sample programs were taken from the Arduino website, and they were used to introduce the syntax that is being employed to interface the microcontroller to the various sensors. An example of these programs is shown in figure 1. For example, the communication between the device (serial) was explained, the selection of one of the pins in the microcontroller (e.g. input), the loop structure (for repeated commands), the initialization of the hardware, were explained in details following different example as the one showed in figure 1. Each string was analyzed so that the educators could have used those as building blocks for constructing a different more complex program if needed.

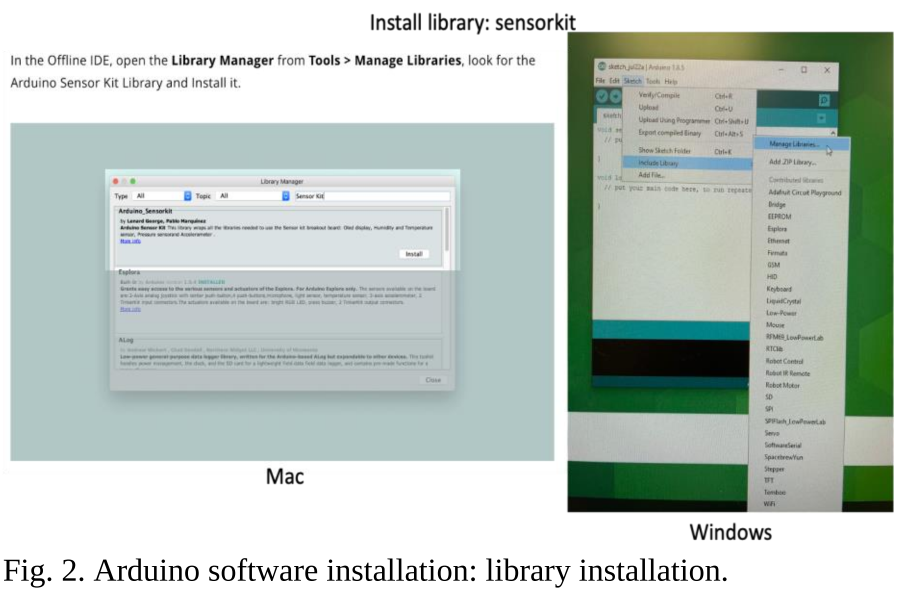

Fig. 2. Arduino software installation: library installation.

After that, the session continued by showing and distributing the hardware. Each of the educators was provided with one Arduino UNO and one sensors board. The microcontroller was shown to be connected to the board containing different sensors (Arduino Sensor Kit). The step-by-step software was downloaded and its installation was shown to the educators that were able to follow up on their own desktops' computers (provided by UNT during the workshop). Moreover, the online version of the software was also illustrated. As part of the hardware installation, the library of the sensor board was installed, and the communication between the controller and the software was shown for both Windows and Mac users (see figure 3).

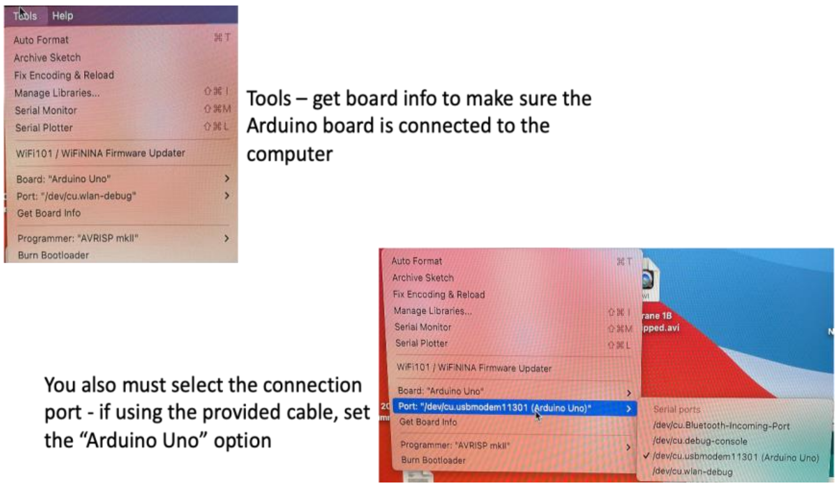

Fig. 3. Arduino UNO: software setting.

After introducing the basic programming and related hardware/software, a new session was introduced on "Microcontroller Application to a Nuclear Power Plant". A 3D printed model of a nuclear power plant was prepared as shown in figure 4, where the Arduino UNO and the Sensor Kit were both connected and placed inside it. The purpose of this session was to have the educators to program simulate the monitoring of a nuclear power plant process (e.g. humidity, temperature, pressure). They had to start the monitoring by pushing the button on the sensor kit, setting a max temperature value and causing an alarm stopping the plant is the temperature was higher than the max temperature value. Educators were working in pairs, and they used the sample programming as basic building block to prepare this new program (shown in figure 5), with the help of the UNT instructors. The built code is an assembly of basic sample programming that were available to the educators; in addition, educators learned logic structures (i.e. if-else).

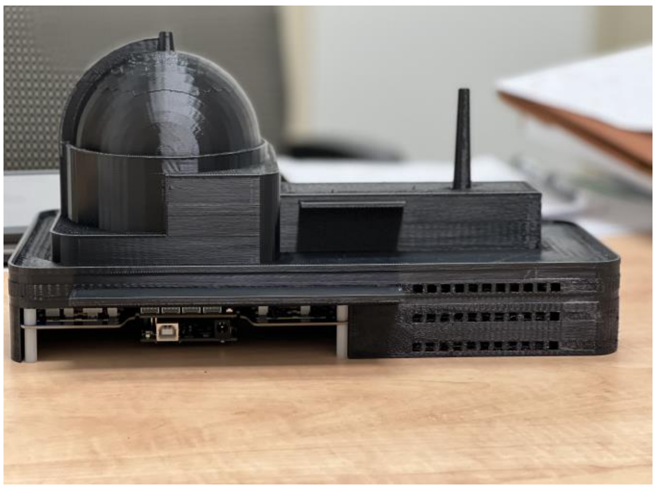

Fig. 4. Photograph of the 3D printed model of a nuclear power station housing the Arduino UNO and sensor kit.

Before the end of the afternoon session, educators were divided into two groups (elementary schools and middle/high schools) to brainstorm about how to implement the STEM content of the workshop into their curricula. Educators that initially were afraid of the programming session, overcome quickly that by gaining more confidence at the end of the workshop as evidenced by the response of a survey attended at the end of the program, showing their level of familiarity with workshop content was high.

```
powerplant
#include "Arduino_SensorKit.h"
#define button 4      // connect button to D4
#define BUZZER 5      // connect buzzer to D5
#define LED 6         // connect LED to D6

int button_state = 0;          // variable for reading the pushbutton status
//float pressure;

void setup() {
  Serial.begin(9600);
  Pressure.begin();
  pinMode(button, INPUT);
  pinMode(BUZZER, OUTPUT);
  pinMode(LED,OUTPUT);
}

void loop() {
  Serial.println("Push the button to test the system");

  bool buttonOpen = false;

  button_state = digitalRead(button);
  if (button_state == HIGH)
  {
    Serial.println("Button pressed!");
    if (buttonOpen == false)
    {
      buttonOpen = true;

    }
    else if (buttonOpen == true)
    {
      buttonOpen = false;
    }
    else
    {
      buttonOpen = false;

    }
  }

  if (buttonOpen == true)
  {
    // Get environmental data
    float temperature = Pressure.readTemperature();
    float pressure = Pressure.readPressure();
    float altitude = Pressure.readAltitude();
  if (temperature >= 20)
  {
    digitalWrite(LED, HIGH); //Sets the voltage to high
    tone(BUZZER, 85); //Set the voltage to high and makes a noise
    delay(1000);//Waits for 1000 milliseconds

    digitalWrite(LED, LOW);  //Sets the voltage to low
    noTone(BUZZER);//Sets the voltage to low and makes no noise
    delay(1000);//Waits for 1000 milliseconds

    Serial.print("ALERT!!!");

    // Print temperature data
    Serial.print("Temperature: ");
    Serial.print(temperature);
    Serial.println("C"); // The unit for  Celsius because original arduino doesn't support speical symbols

    // Print atmospheric pressure data
    Serial.print("Pressure: ");
    Serial.print(pressure);
    Serial.println("Pa");

    // Print altitude data
    Serial.print("Altitude: ");
    Serial.print(altitude);
    Serial.println("m");
  }
  else if (temperature < 29)
  {
    // Print temperature data
    Serial.print("Temperature: ");
    Serial.print(temperature);
    Serial.println("C"); // The unit for  Celsius because original arduino doesn't support speical symbols
  }

  Serial.println("\n");//add a line between output of different times.
 }

 delay(1000);
}
```

Fig. 5. Code designed to monitor a powerplant mock-up model.

3. Outreach Activities

At the end of the workshop, educators were provided lecture materials as well as microcontroller and sensor kits to facilitate their lessons at their institutions. They had implemented into their curriculum the material learned during the workshop into different classes such as math, science, and physics. Based on the collected data (see figure 6),

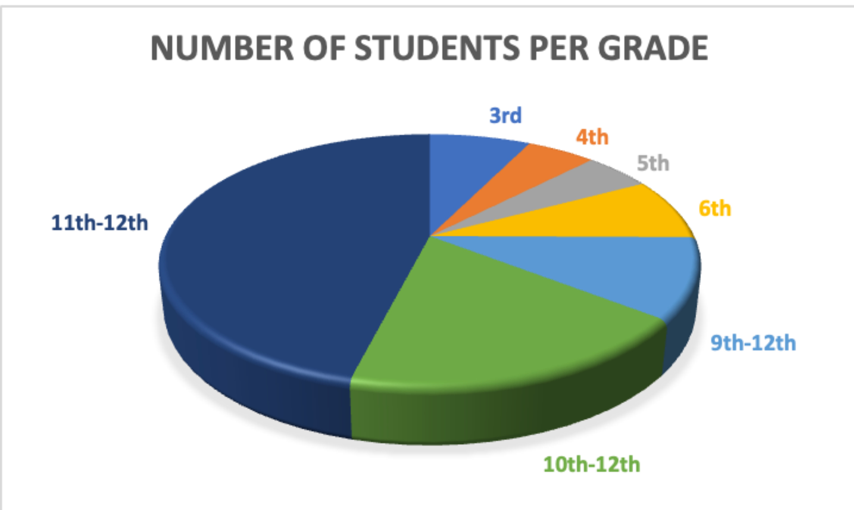

Fig. 6. Demographic of the 780 students involved by the educators' outreach.

STEM educators participated in the workshop eventually reached out to 780 students ranging from 3rd grade to 12th grade at their institutions. Most students involved in the outreach is between 10th and 12th grade. Text-based programming results easier to be introduced at that age than for younger students, which block-based programming may be more appropriate.

4. Conclusions

Overall, participants stated they enjoyed the workshop and provided positive and encouraging comments. Educators prior the workshop had "fear" of programming, especially elementary school teachers. After the workshop, they felt confident and exposed their students to Arduino UNO and programming.

An online survey was also conducted after the workshop to better understand its impact and collect additional feedback. As part of the survey, teachers were asked to provide their level of familiarity with the nuclear power and thermal-hydraulics instrumentation and with microcontrollers, Arduino, and programming. The participants of the survey were all in agreement (very familiar/familiar) about the gain in knowledge about the workshop material.

Acknowledgments

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Biographies

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