BOARD #131: Brewing Interest in Engineering and Computer Science: A Hands-On Coffee Roasting and Brewing Lab for High School Outreach

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Abstract

This paper presents a hands-on outreach activity aimed at increasing high school students' interest in engineering disciplines through a practical, real-world application of coffee brewing analysis and sensor interfacing. The activity, designed for 10th-grade students, introduces basic concepts in engineering, computing, and data analysis by allowing students to roast green coffee beans, collecting and plotting temperature data using Phidget sensors during roasting, and analyze variables in brewed coffee such as pH, turbidity, and extraction yield. By combining curiosity-driven inquiry with interactive, hands-on learning experiences and data analytics, this activity encourages students to explore potential careers in science, technology, engineering, and mathematics (STEM). We discuss the design of the experiment, its implementation, and preliminary results from student feedback. Our findings suggest that this multifaceted, real-world application of engineering principles significantly enhances student engagement and understanding of engineering concepts.

1. Introduction

Engineering education confronts ongoing issues in attracting and maintaining students, particularly at the high school level, where many people acquire long-term impressions about potential career pathways [1, 2]. This problem is especially acute in subjects such as Electrical and Computer Engineering (ECE) and Computer Science (CS), which are crucial for promoting technological innovation and addressing society's growing reliance on digital solutions [3]. Addressing these difficulties necessitates innovative and engaging approaches that explain fundamental engineering and computing principles in an easy and understandable manner while generating curiosity and engagement. This study describes an innovative outreach activity that aims to achieve these objectives by leveraging the familiar and universally engaging process of coffee making as a learning platform.

The lab experiment, titled "Coffee Roasting, Interfacing with Sensors, and Brewing Analysis," was designed to give high school students hands-on, multidisciplinary engineering training. The activity, themed around coffee brewing, introduces participants to key ideas in ECE and CS, such as applying scientific principles to common activities, utilizing sensor technology for ordinary tasks such as coffee brewing, data collection and analysis, process optimization, and. By contextualizing engineering within the accessible activity of coffee brewing, the lab hopes to demystify technical concepts, emphasize their relevance to real-world applications, and inspire students to pursue careers in engineering and computers. The experimental setup used is presented in Figure 1, and a list of all equipment is presented in Table 1.

Figure 1 illustrates the workflow of the coffee roasting lab, demonstrating the integration of various steps in the process. The lab begins with green coffee beans, which are roasted in a controlled environment using a roaster. During the roasting process, data such as temperature and roast time is collected in real-time through the Phidget interface, which connects sensors to a computer for data plotting and analysis. After roasting, the coffee is brewed, and its quality is assessed using measurements of turbidity and acidity (pH) with specialized equipment. This setup highlights the seamless combination of practical roasting and brewing steps with sensor-based data collection and analysis, emphasizing the multidisciplinary nature of the activity.

Coffee with its unique combination of artisanal tradition and high-tech innovation, provides an ideal setting for investigating engineering principles. Coffee roasting and brewing, a seemingly straightforward task performed by millions every day, is intrinsically complex. A “good” cup of coffee requires dialing in an astonishing number of variables ranging from roast quality, bean age, bean origin, washing method, water temperature, ground coarseness, hardness of water, brewing time, and many more. As a result, the coffee industry is highly engineered where every variable is controlled very carefully. From advanced sensors in automated roasting systems to algorithms for optimizing extraction operations, coffee manufacturing exemplifies modern engineering's mix of scientific precision and practical ingenuity. This makes the process both fascinating and educational for the students. The chemistry of coffee extraction, which is impacted by variables such as temperature, grind size, and brew time, provides an excellent framework for teaching students about the value of data analysis, process management, and optimization. This project introduces students to the complex nature of engineering and computing, demonstrating how these fields influence daily life. This study describes the design and implementation of the Coffee Lab activity and discusses its compatibility with educational objectives in ECE and CS. It demonstrates how the activity incorporates key engineering topics in an entertaining and interactive style. It also gives preliminary results from its execution, which show how the exercise affected students' opinions of engineering and computing as career paths. This approach, which provides a real and engaging introduction to engineering and computer science, represents a promising model for inspiring a diverse and enthusiastic generation of future professionals in these fields.

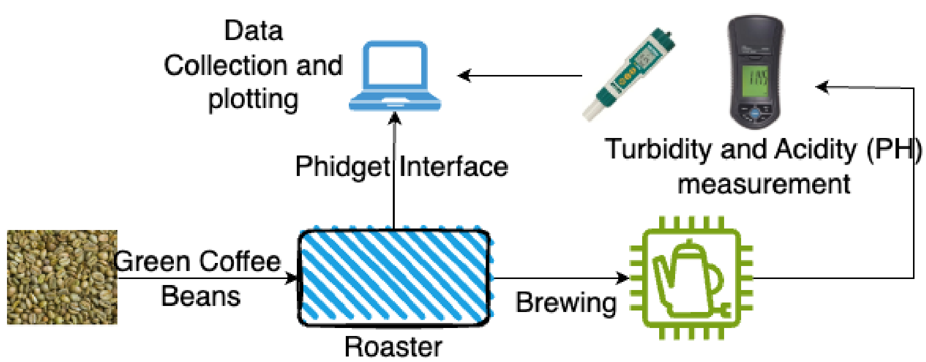

Figure 1: Coffee Roasting Lab

Table 1: Coffee Equipment and Materials Categorized by Function

Roasting	
Behmor Coffee Roaster	Roaster
Behmor Modification Kit	Roaster Modification Kit
Silicone Mitts	
Data Collection	
Thermocouple (Phidgets)	Analog Temperature Sensors

Thermocouple Cable	Cable to Connect to Hub
Phidgets Hub	For connecting to a Computer
Oakton Instruments pH Tester	pH Tester
Digital Coffee Refractometer	Refractometer
Brewing and Tasting	
Baratza Encore Grinder	Bean Grinder with precise size control
Hario V60 Coffee Dripper	Coffee Dripper
Gooseneck Kettle	Electric Kettle with Temperature Control
Digital Coffee Scale	Precision Scale
V60 Filters	Filters
Bodum Chambord French Press	French Press
Pure Caffeine Capsules	Caffeine for comparing taste
Citric Acid Powder	Establish acidity baseline
Compostable Coffee Cups	Coffee Cups
Hario Cupping Spoon	Spoon
Vacuum Insulated Carafe	Storing Coffee
Glass Measuring Cup	Measuring Cup
Coffee Bags	Reusable Coffee Bags

2. Design and Implementation

The design and implementation of the "Coffee Roasting, Interfacing with Sensors and Coffee Brewing Analysis" lab activity was guided by the goal of providing high school students with a hands-on introduction to engineering and computing concepts. This section outlines the objectives, materials setup, and the various stages of the lab, from interfacing sensors to data analysis. The primary objectives of the lab experiment include:

1. Introduce students to sensor interfacing and data collection techniques
2. Familiarize students with variables involved in a common process (coffee roasting and brewing)
3. Teach basic data analysis and visualization skills
4. Encourage critical thinking about process optimization
5. Demonstrate the interdisciplinary nature of engineering

These objectives were created to be consistent with the Next Generation Science Standards (NGSS) [4], namely the engineering design methods and cross-cutting concepts. By including students in a multifaceted engineering project, we aim to improve their ability to ask questions, analyze data, and generate explanations, all of which are critical activities in the NGSS framework. The lab was created to teach participants about sensor technology, data collecting and analysis, and process optimization while also illustrating how these principles may be applied to a real-world scenario. Aside from technical knowledge, the exercise aimed to pique interest and build an understanding of the vital role of engineering in everyday life. The addition of an interactive and recognizable topic, coffee making, was meant to make the learning experience relatable and engaging, especially for students with limited exposure to STEM disciplines.

The lab's materials and setup were carefully chosen to balance accessibility and technical depth. Participants were given needed equipment such as a Coffee Roaster, Phidget analog sensors, coffee beans, a roaster, a grinder, brewing supplies, a pH meter, and a turbidity meter. In addition, computers with pre-installed data gathering software were employed to communicate with the sensors and record measurements. This system allowed students to examine the practical and computational sides of engineering. The materials and equipment were carefully chosen to be user-friendly while also allowing for exploration and learning. The integration of sensor technologies and computer interfacing was an important aspect of the lab. Students were charged with connecting Phidget analog sensors to a computer and utilizing software to collect real-time data while roasting and brewing coffee. This stage taught participants about the basics of data acquisition systems, emphasizing the importance of sensor calibration, data accuracy and statistical significance, and troubleshooting. By completing these assignments, students learned how sensors monitor and control variables in engineering systems.

The lab's coffee roasting and brewing processes provided a practical setting for investigating engineering principles through hands-on activities. Students began by selecting and weighing different types of coffee beans, such as Colombia Supremo and Guatemala Antigua, using a precision weighing machine, introducing them to the importance of measurement accuracy and precision in engineering. Before roasting, they preheated the roaster, learning about thermal dynamics and the role of temperature control in process stability. During the roasting process, students monitored essential variables such as temperature, roast time, and airflow, gaining insights into process control and optimization. They also measured the beans' weight before and after roasting, observing how chaffing reduced weight, which introduced concepts of material properties and mass conservation.

After roasting, students ground the beans into powder using various grinder settings, which produced a range of coffee particle sizes and enabled them to explore the role of mechanical engineering principles in the process. Students observed how particle size impacts flavor profile, linking mechanical precision's importance to optimizing downstream processes. The students then brewed coffee using methods such as drip brewing or a French press, applying chemical engineering concepts to assess variables like pH and turbidity, highlighting the importance of solution chemistry and quality control in product development. This structured, multidisciplinary approach emphasized how engineering principles intersect with everyday operations, encouraging active engagement and critical thinking at each stage.

Data gathering played a crucial role in the lab, highlighting the importance of consistency and repeatability in engineering studies. Students used thermocouples connected to the Phidget interface to collect real-time temperature data during roasting. The thermocouple generated a small voltage corresponding to the temperature difference between its junctions. This voltage signal was sent to the Phidget device, which underwent amplification and analog-to-digital conversion. The Phidget device processed the signal into digital temperature data, subsequently fed into Artisan software for visualization. By interfacing the thermocouple with the Phidget device, students explored how raw voltage signals are amplified and processed into usable data, gaining insights into ECE concepts such as signal conditioning, analog-to-digital conversion, and calibration. Artisan software displayed dynamic plots of temperature profiles, allowing students to monitor changes and annotate critical events such as "beans loaded," "first crack start," and "roast end." These activities emphasized the integration of hardware and software systems, demonstrating how engineering tools facilitate real-time monitoring and data-driven decision-making.

Students also learned CSC concepts through their interactions with data acquisition and management systems. They explored how data is structured, transmitted, and processed between hardware and software systems. Artisan software introduced students to real-time data visualization, highlighting the role of algorithms in generating dynamic plots. Additionally, students organized sensor readings, annotated event timestamps, and analyzed raw data, reinforcing skills in data management and the fundamentals of software integration. These exercises illustrated the interdisciplinary nature of ECE and CS, bridging hardware interfacing with computational systems for real-world applications.

The lab concluded with a focus on data analysis and visualization. Using the collected data, students calculated key metrics such as the brew ratio, total dissolved solids (TDS), and extraction yield. They created visualizations, including graphs and plots, to identify patterns and analyze variability between trials. These activities emphasized statistical analysis techniques and the importance of data interpretation in engineering. Students gained practical experience in analyzing real-world datasets, enhancing their ability to communicate findings and make evidence-based decisions. The integration of ECE and CS concepts at every stage of the lab highlighted the power of multidisciplinary engineering approaches in optimizing processes and solving complex problems.

The Coffee Lab activity successfully integrated theoretical and practical elements of engineering and computing into a cohesive learning experience. By combining sensor technology, data analysis, and hands-on experimentation within the context of coffee brewing, the lab engaged students in a multidisciplinary exploration of ECE and CS concepts while demonstrating their real-world applications.

3. Results

This outreach engagement gave high school students a hands-on introduction to engineering principles using the compelling setting of coffee roasting and brewing. The activity's goal was to show the importance of engineering in everyday processes while also stimulating interest in engineering and computing careers by using sensor technologies, data analysis, and process optimization. Surveying participants is an important step in determining the efficacy of outreach operations. Educators can gather comments on the activity's clarity, accessibility, and impact, as well as highlight areas for improvement. To assess the lab's success, nearly 150 student participants were given a voluntary survey. A total of 107 replies were received, ensuring a sufficient sample size for analysis as presented in Table 2.

The poll results were good, with the majority of respondents rating the activity favorably in all areas. Students were particularly impressed by the lab's ability to connect engineering principles to real-world circumstances, with 100% agreeing or strongly agreeing that it helped them understand these concepts. Furthermore, 66.7% of participants expressed a renewed interest in pursuing engineering courses or jobs, demonstrating the lab's ability to inspire the future generation of engineers.

Furthermore, correlation analysis was done on the data, as shown in Table 3. Correlation analysis of survey items provided numerous crucial insights. The strongest correlation (0.89) was found between understanding engineering principles (Q3) and increased interest in Engineering and Computer Science (Q4), implying that students who felt they understood the principles better were more likely to express a desire to pursue ECE careers. A moderate positive association (0.65) was discovered between ease of following the technique (Q2) and knowing engineering concepts (Q3), indicating that a well-defined approach improves conceptual knowledge. Similarly, clear aims (Q1) had a moderate association (0.63) with the ease of following the method (Q2), emphasizing the significance of well-communicated objectives in facilitating the activity. Surprisingly, no association (0.00) was found between clear objectives (Q1) and greater interest in ECE (Q4), showing that, while clear objectives are necessary for execution, they have no direct impact on students' professional interests. Finally, procedure clarity (Q2) exhibited a weak positive correlation (0.35) with increased interest in ECE (Q4), implying that, while significant, procedural clarity has a limited impact on kindling interest in ECE career paths. These connections provide useful insights into how different parts of the lab experience interact with one another and contribute to the overall goal of growing interest in ECE. The strong relationship between comprehending engineering principles and increasing interest in ECE is especially remarkable, since it demonstrates the efficacy of hands-on, applied learning in inspiring future engineers.

Table 2: Post-survey results from outreach activity (N=107)

Question #	Survey Questions	Score 1-Low, 5-High
1	The objectives of the lab were clearly communicated.	3.77
2	The procedure outlined was easy to follow and understand.	3.68
3	The lab activities (roasting, brewing, data analysis) helped me understand engineering principles in real-world scenarios.	3.84
4	This lab has increased my interest in pursuing further studies or careers in engineering and computer science.	3.76

Table 3: Post-Survey correlation analysis

Question	Q1	Q2	Q3	Q4
Q1	1.00	0.63	0.41	0.00
Q2	0.63	1.00	0.65	0.35
Q3	0.41	0.65	1.00	0.89
Q4	0.00	0.35	0.89	1.00

Further statistical analysis was conducted, as presented in Table 4, highlighting the t-test results for each survey item, demonstrating significant positive differences from the neutral score of 3 across all categories. Q1 achieved a mean score of 3.77 and a t-statistic of 10.2471 ($p < 0.0001$), indicating that students found the lab's objectives to be clearly conveyed. Similarly, Q2 yielded a mean score of 3.68 and a t-statistic of 7.9015 ($p < 0.0001$), reflecting that participants generally found the outlined steps straightforward. The highest mean score (3.84) and t-statistic (11.1245) were associated with Q3 strongly supporting the effectiveness of the lab in enhancing students' understanding of engineering concepts ($p < 0.0001$). Finally, Q4 garnered a mean score of 3.76 and a t-statistic of 9.4615 ($p < 0.0001$), demonstrating the lab's success in fostering greater interest in Electrical and Computer Engineering. This provides strong evidence that the outreach activity had a positive impact across all measured aspects.

Table 4: t-test for survey results

Question	Mean	Std Dev	t-statistic	p-value
Q1	3.77	0.80	10.2471	< 0.0001
Q2	3.68	0.92	7.9015	< 0.0001
Q3	3.84	0.81	11.1245	< 0.0001
Q4	3.76	0.84	9.4615	< 0.0001

Student feedback on this lab was overwhelmingly positive, reflecting its engaging and educational nature. Many students appreciated the lab's interactive elements, with one student enthusiastically stating, "No, I was super sucked into the lab," while another described it as "very educational. 10/10." The sensory experiences of the lab also stood out, as one participant commented, "I enjoyed seeing/smelling the popping of the beans." The overall enjoyment was evident when they were asked for any potential improvements in remarks such as, "No, it was really cool," and "Nah, it’s awesome as it is.".

Integration of Engineering Disciplines

A key feature of this lab is its integration of concepts from various engineering disciplines:

- Computer Science and Engineering: Students engage with Computer Science and Engineering through sensor interfacing and basic programming tasks.
- Chemical Engineering: Concepts from chemical engineering are applied in pH measurement and understanding extraction processes.
- Mechanical Engineering: The use of coffee roasting and grinding equipment introduces elements of mechanical engineering.
- Data Science: Data collection, analysis, and visualization
- Process Engineering: Optimization of coffee brewing process

4. Conclusions and Future Work

This work focuses on designing and implementing an innovative outreach program that introduces high school students to essential engineering ideas through the engaging and relevant context of coffee roasting and brewing. The activity met its goals by including sensor interface, data collecting, and analysis into a hands-on learning experience and provided students with a thorough introduction to interdisciplinary engineering. The lab effectively taught students about sensor technology and data-collecting methodologies, connecting theoretical knowledge with practical application. Students experimented with the variables involved in coffee roasting and brewing, learning how these parameters affect outcomes in a typical procedure. Participants learned important skills in understanding patterns and recognizing significant insights through structured data analysis and visualization exercises, which fostered critical thinking regarding process optimization.

A noteworthy effect of the lab was its capacity to demonstrate the multidisciplinary nature of engineering by combining components of electrical and computer engineering, data science, and chemical processes in a single activity. Students' feedback highlighted the activity's impact, with many expressing a renewed interest in pursuing engineering education and professions. The high participation level and favorable feedback demonstrate the potential of hands-on activities to inspire future engineers and bridge the gap between abstract concepts and real-world applications. Finally, this activity highlights the value of novel, multidisciplinary methods to engineering education. It serves as a model for future outreach efforts, highlighting the significance of relevant, hands-on learning experiences in fostering interest and comprehension in engineering areas. Future iterations of the lab could build on its interdisciplinary approach by introducing new factors or technology to increase its educational value and impact.

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