



# Developing Sensor Labs From College to High School and Beyond

M. Elizabeth England MsEd<sup>1</sup>, Brittany Langevin<sup>2</sup>, Dr. Jeffrey M. Halpern<sup>3</sup>

<sup>1</sup>Winnisquam Regional High School, <sup>2</sup>Noble Middle School, <sup>3</sup>University of New Hampshire Department of Chemical Engineering



## Why Developing a Sensor Course has Value

Sensors are a simple and promising analytical tools (Figure 1) to help students understanding important concepts of enzymatic analysis and electroanalysis systematically [1].

Sensors are a part of our daily lives [2] to be used to:

- detect harmful chemicals in air, water, and earth
- protect or monitor our health
- growing field in industry
- better understand the world we live in.

Sensors should be [1, 2]

- Resilient
- Reliable
- Stable
- Cost-effective
- Portable

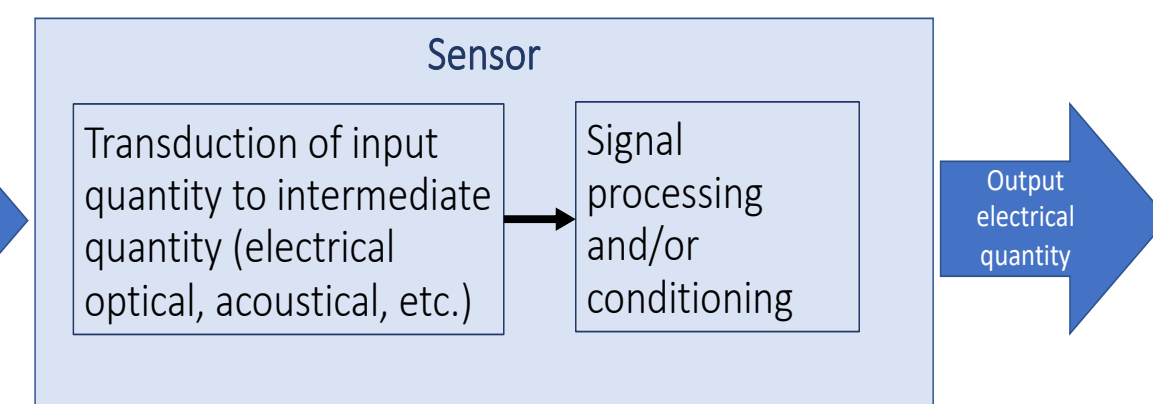


Figure 1: Sensor principle. Schematic diagram of sensor that produces and electrical output in response to the presence of an input quantity.

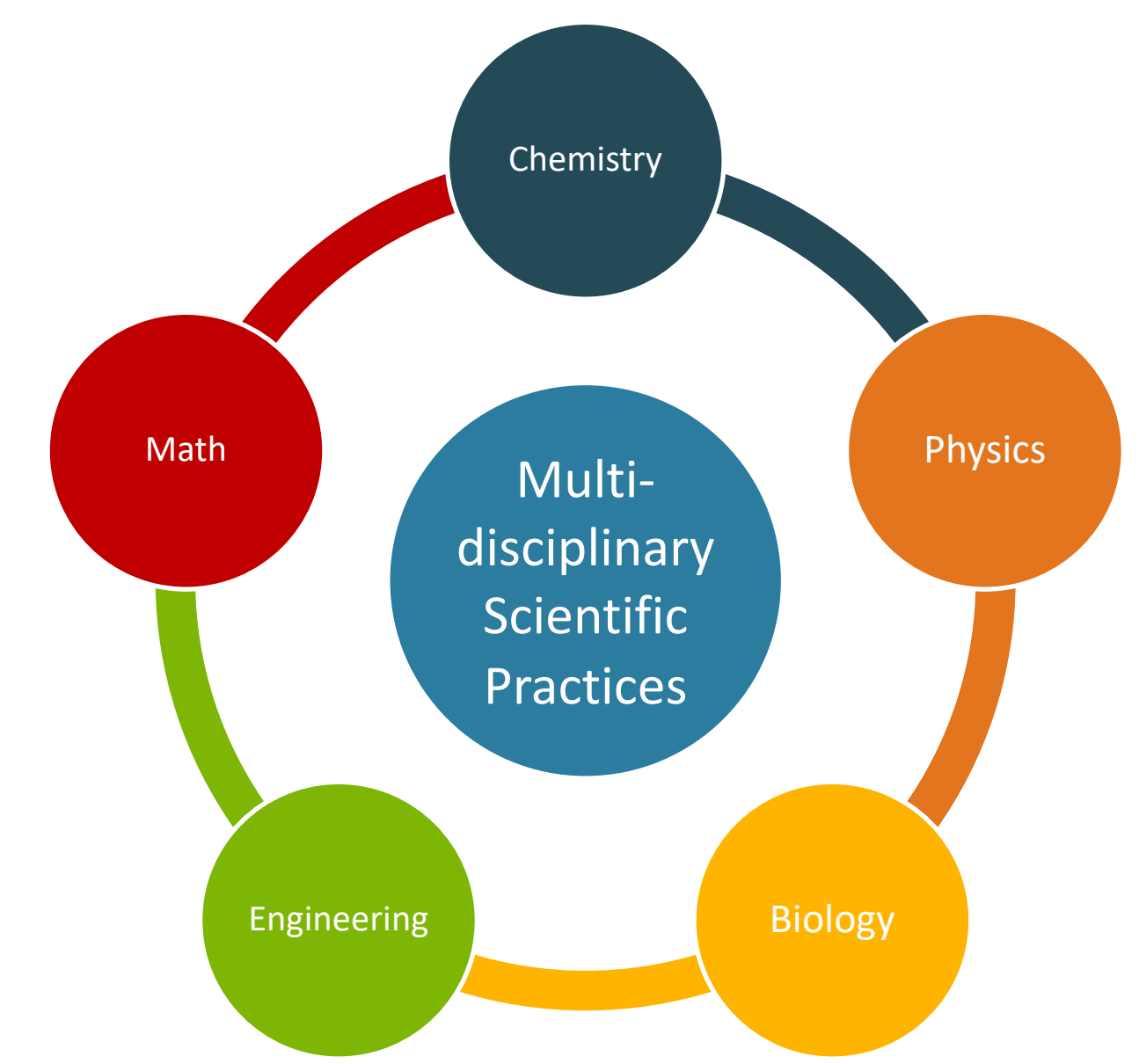


Figure 2: Sensors are Multidisciplinary Science Practice

## Background on Cyclic Voltammetry (CV)

- CV is a powerful tool for to exam electrochemical properties of chemicals by studying the electrochemical reaction mechanism [2].
- Voltage is applied and current is measured to determine the kinetic information (Figure 3).
- (Figure 5) Potentiostat controls the voltage difference between electrodes contained in an electrochemical cell [2].

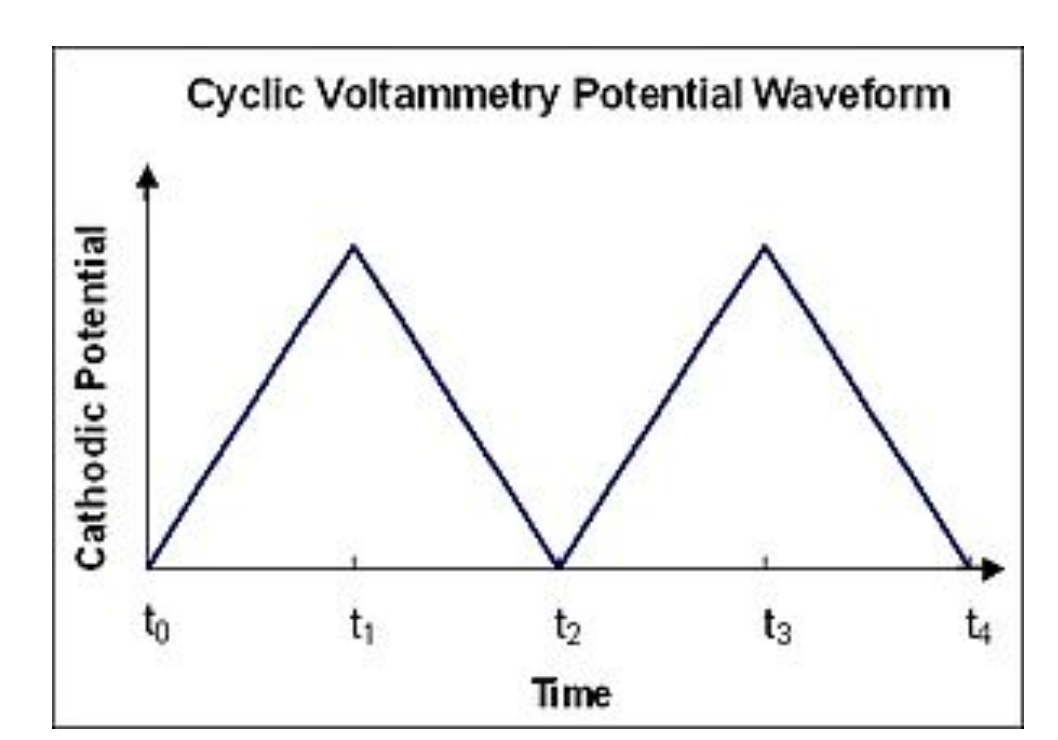
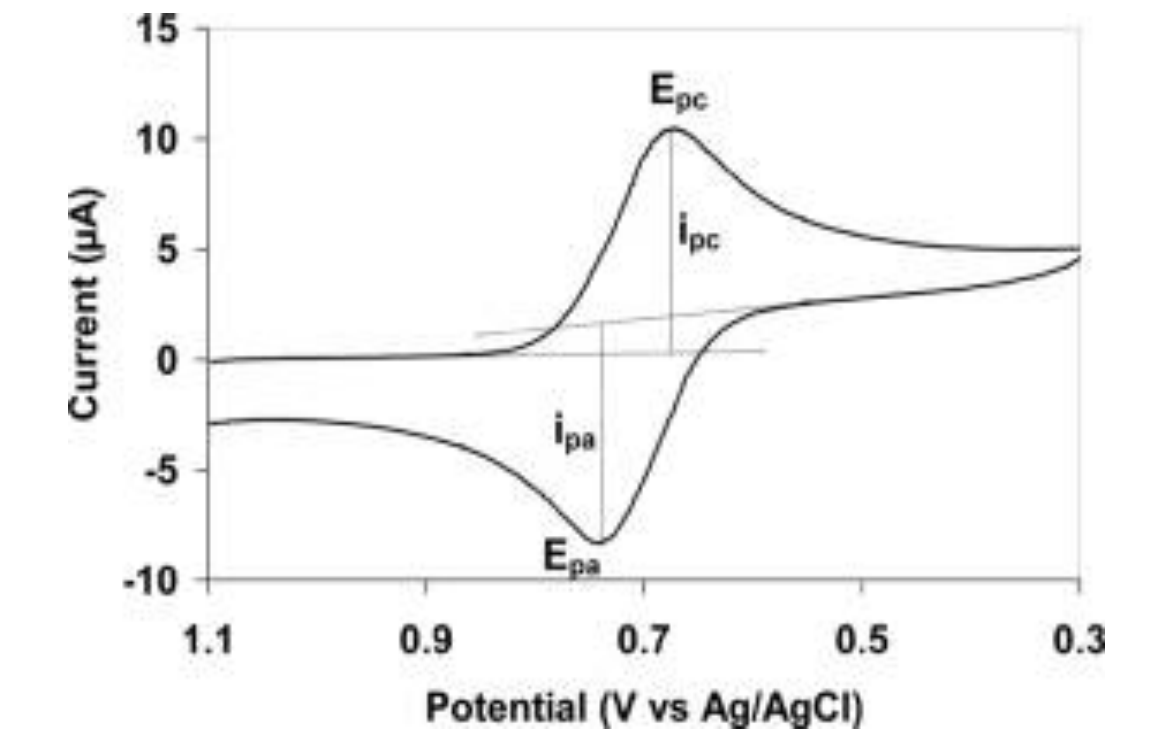


Figure 3: (Top) Potential versus time program for CV showing the reversed and forward linear potential ramp. (Bottom) CV of measured current versus applied potential.



Source: Unknown Author is licensed under CC BY-SA

## Application in Chemical and Biosensor College – Application Labs

### Experiment 1: Dopamine Detection - Understanding the Role of Concentration

As an introduction to sensors, this experiment has multiple components:

- 150 µM concentration of dopamine in a phosphate buffer saline (PBS).
- Produce a serial dilution of 7 different concentration plus a 0 µM of pure PBS as baseline.
- Build the sensor using shot glass, cap, working (indicator) electrode, reference electrode, and auxiliary electrode.
- Analyze the dopamine oxidation results to look for the clear maximum or peaks associated with the electric currents.

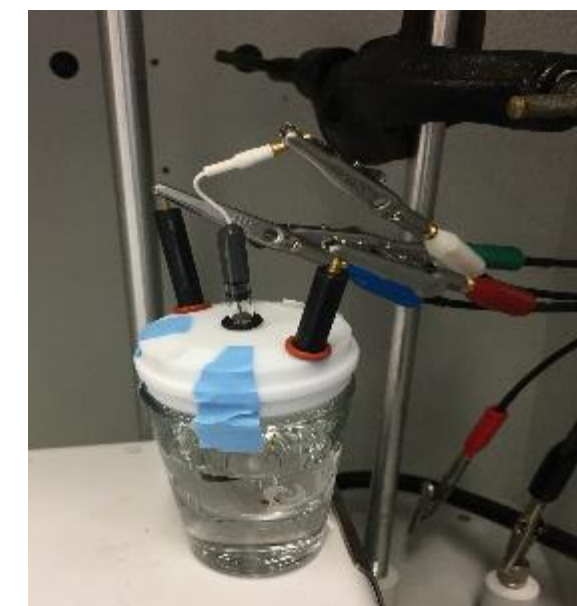


Figure 4: Three Electrode Cell



Figure 5: Gamry Potentiostat

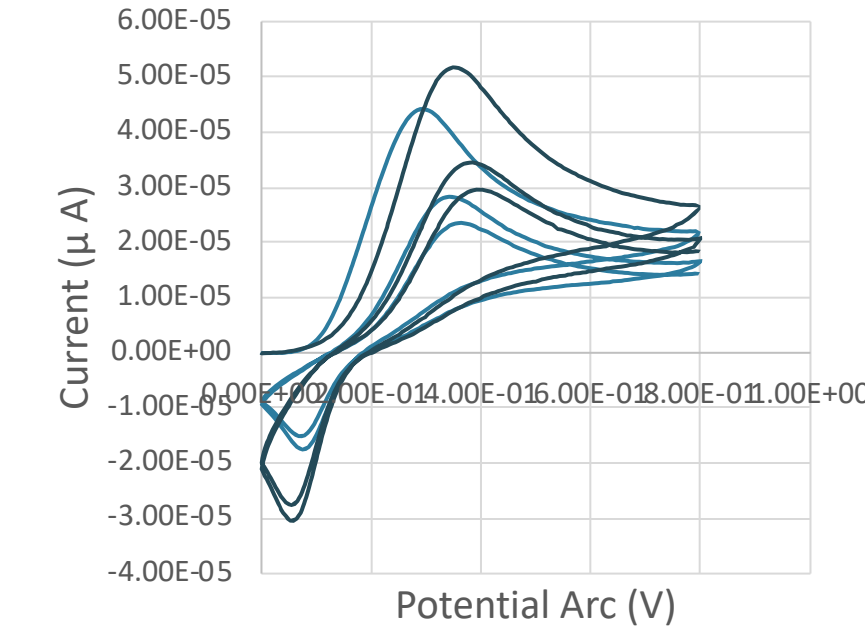
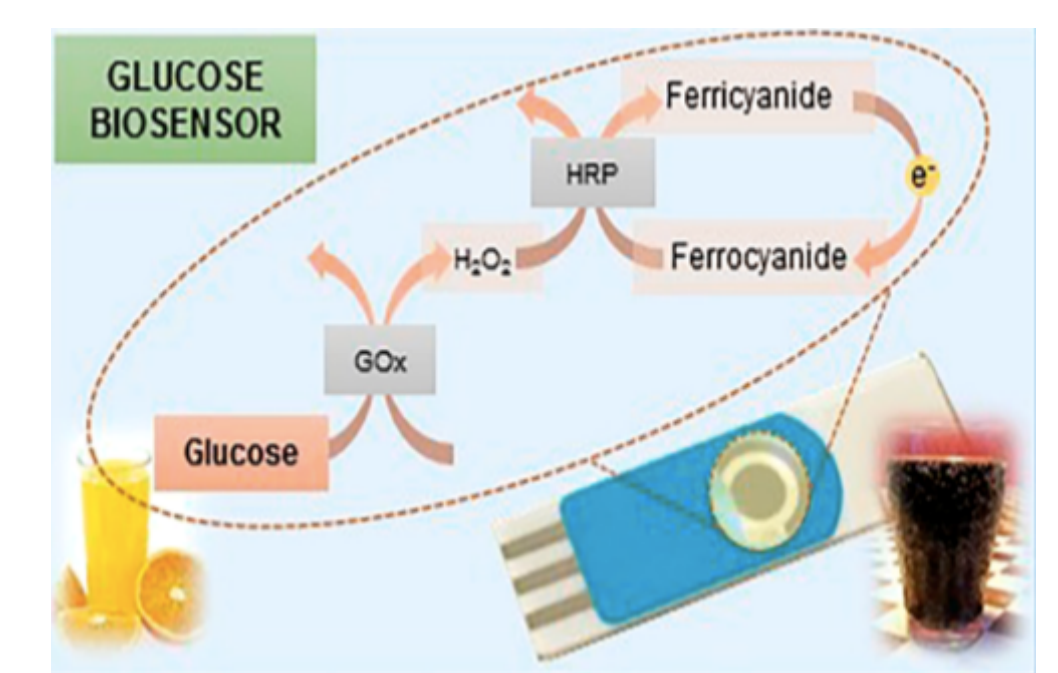


Figure 6: CV Output for Dopamine on three separate runs.

### Experiment 2: Glucose Biosensors Implementing Basic Analytical Concepts [3]

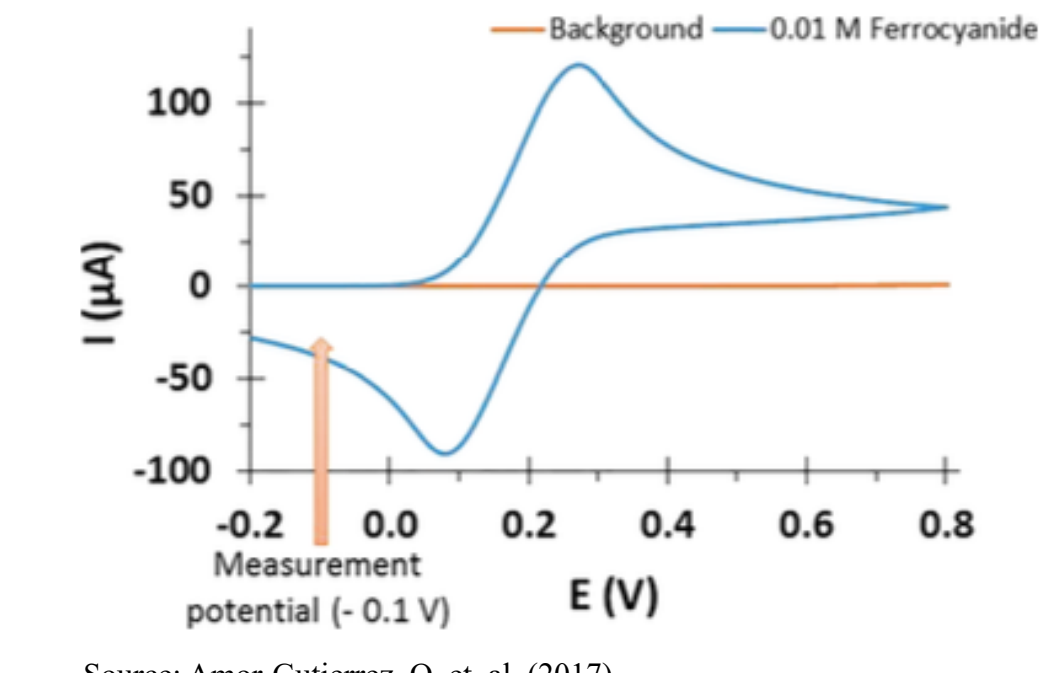
The components of this experiment include:

- Evaluation of the ferro/ferricyanide system using cyclic voltammetry to set the detection potential.
- Optimization of the concentrations of enzymes.
- Calibration of the biosensor and evaluation of the sensitivity (Figure 8).
- Determining glucose in real food samples (Figure 7).



Source: Amor-Gutierrez, O. et. al. (2017)

Figure 7: Fabricate an enzymatic glucose biosensor using a disposable screen printed electrode.



Source: Amor-Gutierrez, O. et. al. (2017)

Figure 8: Cyclic voltammogram recorded in 0.1 M Tris-HNO<sub>3</sub> buffer solution (pH 7.0) (background, orange) and in 0.01 M ferrocyanide (blue). [2]

### Experiment 3: Paper Based Devices for Detecting Acetaminophen and Phenacetin [4]

The purpose is to detect analytes using paper based device.

- Synthesis of the analytes acetaminophen (Figure 9) and phenacetin (Figure 10)
- Fabrication of paper-based devices, using eyeliner, acrylic spray paint, or wax-printing, for sensing of those analytes
- Use newly fabricated devices for successful qualitative and quantitative analyte detection.

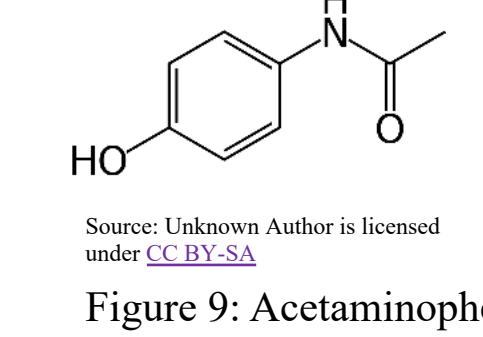


Figure 9: Acetaminophen

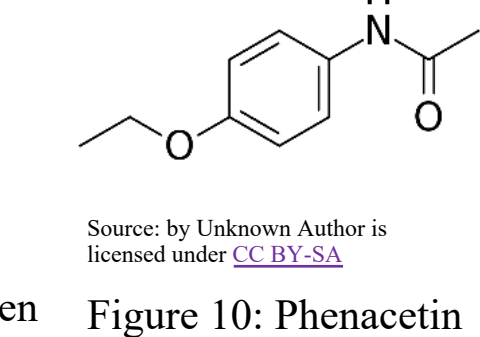
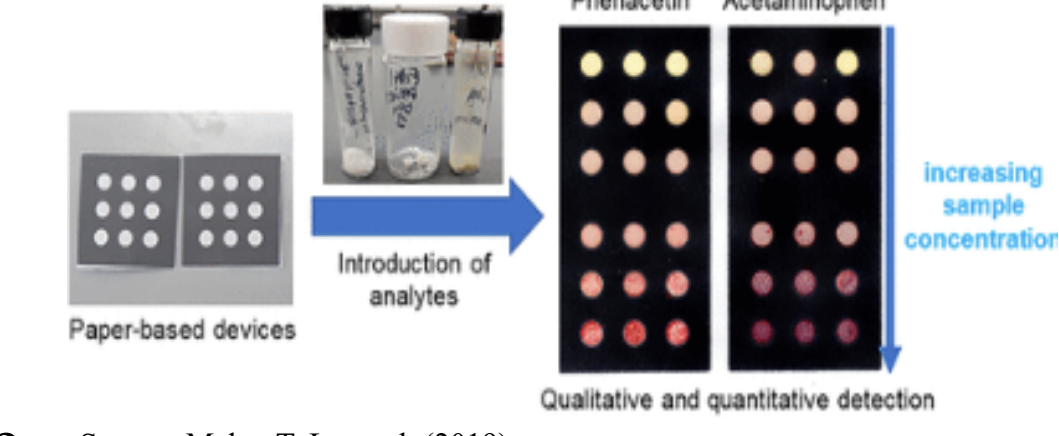


Figure 10: Phenacetin



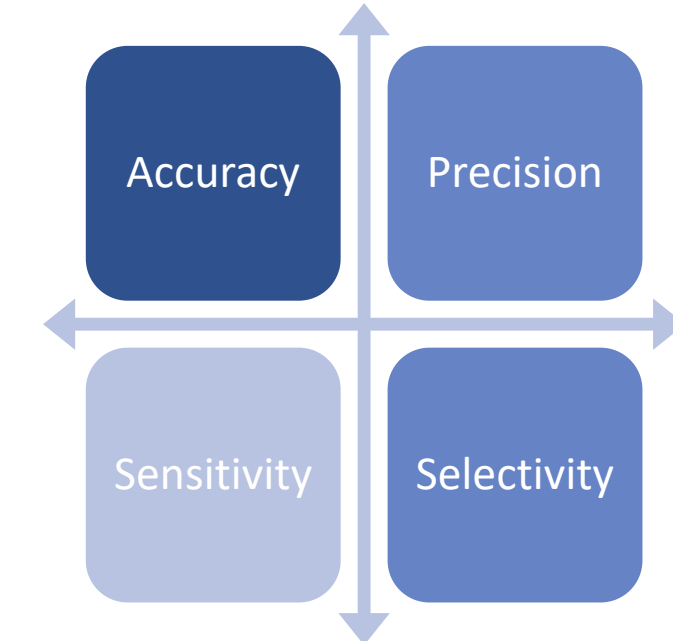
Source: Mako, T. L. et. al. (2019)

Figure 11: The detection process

## Chemical and Biosensor High School Classroom Experience

### Overarching Ideas & Perspective

- Sensor labs can be completed in different classes and scaffolded to help students at all levels of understanding.
- Connecting the need, diversity, and complexity of sensors to traditional science practices and activities.
- Understanding the importance of accuracy, precision, sensitivity and selectivity.
- Labs with commonalities in learning goals.



## Hurdles for Implementing labs in the HS Classroom

1. Cost of supplies
2. Access to devices for measuring CV
3. Keeping current with evolving sensor technology and practices.
4. District and Department “buy-in”
5. Transporting students to outside resources

## Labs in the High School Classroom

### Experiment 1: Dopamine Detection & Understanding the Role of Concentration

This lab will be structured as a Process Oriented Guided Inquiry Learning (POGIL). **PHYSICS**

Essential Questions: *What is the difference between a physical and chemical property or change. What occurrences signify the type of change occurring in everyday processes?*

### Experiment 2: Glucose Biosensors Implementing Basic Analytical Concepts

Using an Argument Drive Inquiry (ADI) framework allow students design the lab base on parameters. **CHEMISTRY & INTEGRATED SCIENCE**

Essential Question: *What challenges are faced related to the achievement of accurate and reliable glucose testing?*

### Experiment 3: Paper Based Devices for Detecting Acetaminophen

This lab will be structure very similar to the college version and taught near the end of the semester. **CHEMISTRY**

Essential Question: *How does matter undergo changes and how do we use chemical equations?*



## Sensors Available at Winnisquam Regional High School

Gas Pressure Sensor	Motion Detector	Magnetic Field Sensors
pH sensors	Oxygen Sensor	Light Sensor
Proximity Sensor	Carbon Dioxide Sensor	Barometer Sensor
Conductivity Sensors	Dissolved Oxygen Sensor	Turbidity Sensor
Colorimeter	UVB Sensor	Heart Rate Monitor
Relative Humidity Sensor	Flow Rate Sensor	Force Sensor
Fitbit/Apple Watch	Cell Phone	Wii
Food Heating Units	Score Board	Lights
Door Alarms	Fire Alarms	Can you think of others?

## Translating to the STEM and Middle School Classrooms

### Raspberry Pi - It is not just for dessert!

- Raspberry Pi (Figure 13) is a low cost, small computer which allows the student become an engineer and a computer programmer. [5]
- Device can be used to expand the scope sensors into classroom



Figure 13: Raspberry Pi Device

### Pre-Defined Raspberry Pi Sensor Labs

- What lurks in your basement? Radon Detector – Integrate Raspberry Pi and Giger counter. [6]
- When something happens in chemistry class. Gas and Smoke Alarm – How sensitive can they be? [6]
- Where is the air conditioning when you need it? Temperature and Humidity Data Logger – Turning up the heat or opening a window. [5]

## Access to Materials

All lab materials produced by authors are available on the web. As new materials are developed and adapted they will be included.



Please respect the content.

## Future Work

Designing a semester course on sensors for high school students (20/21 academic year)

## References

1. Janata, J. (2009). Principles of Chemical Sensors (2<sup>nd</sup> Ed). New York, NY: Springer Science.
2. Vetelino, J. and A. Reghu. (2011). Introduction to Sensors. Boca Raton, FL: CRC Press, Taylor Francis Group.
3. Amor-Gutierrez, O., E. C. Rama, M. T. Fernández-Abedul, and A. Costa-García. (2017). Bioelectroanalysis in a Drop: Construction of a Glucose Biosensor. J. Chemical Education 94: pp.806-812. DOI: 10.1021/acs.jchemed.6b00948
4. Mako, T. L., and M. Levine. (2019). Design, Implementation, and Evaluation of Paper-Based Devices for the Detection of Acetaminophen and Phenacetin in an Advanced Undergraduate Laboratory. J. Chemical Education DOI: 10.1021/acs.jchemed.9b00028.
5. Karvinen, K. & T. Karvinen. (2014). Make: Getting Started with Sensors: Measuring the World with Electronics, Arduino, and Raspberry Pi. Sebastopol, CA: Maker Media.
6. Santos, R. and S. Santos. (2018). 20 Easy Raspberry PI Projects. San Francisco, CA: No Starch Press.

## Acknowledgements

This research was supported with funding from the National Science Foundation’s Research Experience for Teachers in Engineering Grant (ENG-1711781). Special thanks to Steven Hale, Allison Wasiewski, Emily Ziino, Priyanka Nadar, Charles Gasperoni, Zahra Panahi, and all researchers in SEEDS Lab for all their help in and outside of the lab. Thank you also to the Joan & James Litzer Center for Mathematics, Science, and Engineering Education at University of New Hampshire for the opportunity to expand my science knowledge base.