Integration of Inquiry-Based Learning (IBL) with Real World Problem-Solving

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ABSTRACT

The use of inquiry-based learning (IBL) labs related to real-world issues in the 21st century has been the focus of our problem based labs. Every day the quality and quantity of water resources are expected to define the 21st century and the future of the planet which is nearly seven billion people. The electroanalytical, analytical techniques and various instrumentation utilized in the inquiry-based learning labs were to educate our students about the real world based problems and environmental concerns and how to detect various carcinogenic compounds. The use of learning various techniques to analyze the samples involved voltammetry, Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (EDX). The undergraduate students with carbon nanotubes integrated with conductive polymers and nanoparticles as modified conductive working electrodes to detect various carcinogenic compounds by various voltammetric techniques without the need of prior separation were the main focus of these inquiry- based labs. The collaboration with universities and industry have allowed these labs to be IBL (Inquiry-Based Learning) with real-world detection of heavy metals in water to carcinogens thus assist students in understanding the importance of chemistry.

Keywords: Inquiry Based Learning (IBL)/Collaboration with universities and industry setting, assessment. Organic compounds[Catechol, Phenol], redox chemistry, enhanced electrocatalytic activity-modified electrodes, everyday chemicals : Vitamin C also known as ascorbic acid (AA), heavy metals (Pb, Cd and Hg), Voltammetry, and Scanning Electron Microscope.

1. INTRODUCTION

The beginning professors early in their career teaching do use cookbook /textbook labs. The cookbook/textbook labs do not relate to real-world problems and typically an answer to solve the lab problem may be found from a basic internet search. The IBL labs required undergraduate students to learn novel techniques such as how to modify a bare electrode with a conductive polymer utilizing a potentiostat. Once the electrodes were modified then the analysis of the carcinogenic compounds (catechol, phenol) to the heavy metals had to be determined by voltammetry. The in-depth learning of the various voltammetry techniques was required to determine what would achieve the optimum detection from 1,2-dihydroxybenzenes to heavy metals.

The collaboration with the universities (University of Central Florida, The Ohio State University) and the industries (AK Steel and Bowser-Morner) has assisted our undergraduate students with real-world instrumentation to real-world analysis of various organic and inorganic compounds. During the manufacturing process industry shared with our students how common exposure to carcinogenic compounds such as phenol and catechol may occur. Catechol and phenol has been used in dyes, rubber, lubricating oils, cigarettes to pharmaceuticals. Common health issues such as convulsions and depression can be the cause due to absorption of catechol and phenol thru the skin. Heavy metals such as lead and cadmium are dispersed in the environment primarily by way of anthropogenic acitivities. These activities include mining/smelter, manufacturing of industrial products (batteries), fuel burning and waste incineration.

Expensive high-tech equipment such as inductively coupled plasma emission spectroscopy , atomic absorption spectroscopy, and inductively coupled plasma mass spectroscopy are typically used in the detection of heavy metals but need to be carried out on-site and require prior sample separation before analysis. Therefore, due to these issues noted with the high-tech instrumentation our students learn with by the inquiry-based lab how to detect heavy metals with voltammetry (inexpensive and no prior sample preparation/separation). Our students were engaged into the voltammetry techniques and learned the advantages of Square Wave Anodic

Stripping Voltammetry (SWASV) over the Differential Pulse Voltammetry (DPV) and the Cyclic Voltammetry (CV). Assessment of our students learning with IBL (labs) is a vital aspect. Our pre-service undergraduate students involved in these inquiry modules were given the Ohio Assessment Education (OAE) test from the years of 2017 to 2019.

2. EXPERIMENTAL

Materials/Equipment

Bare carbon, bare platinum and bare gold electrodes will be compared as the working electrodes. Ascorbic acid, catechol, phenol, phosphate buffered solution, sulfuric acid. CV, DPV and SWASV measurements were carried out on Bioanalytical System Epsilon potentiostat, utilizing three electrodes in electrochemical cells. These cells include a Ag/AgCl (3 M NaCl) reference electrode, platinum wire auxiliary electrode, and {Carbon working electrodes (Carbon 1.6 mm diameter, Bioanalytical System Inc), three electrode compartment cell. To make the dispersion of Carbon Nanotube (CNT)-poly-3-hexylthiophene (P3HT) by mixing 20 mg MWCNT with 20 mg P3HT plus 20 mL tetrahydrofuran (THF) and ultrasonicated for 1 hr. Lead (II) standard and Cd (II) standard and nitric acid. Multiwall Carbon Nanotube (MWCNT) from Nanolab with a diameter of 10-20 nm and length about 5-20 μm. Poly(4-styrenesulfonic acid), PSS, sodium borohydride, , 5% nafion solution, and silver nitrate. 10mg MWCNT dispersed in 10 mL deionized water with 0.3 mL , 18 wt % PSS and 7.5 mg 5% Nafion solution. The 5.3 mg of silver nitrate was dissolved in MWCNT dispersion by the addition of 10 mg, 10% sodium borohydride solution. (All CNT synthesis carried out with UCF-Dr. Lei Zhai)

3. RESULTS/DISCUSSION

The beginning step of learning voltammetry /electrochemistry techniques starts with cyclic voltammetry (CV) since it focuses on detection of higher concentrations before proceeding to lower detection concentrations with other voltammetry techniques such as Differential Pulse Voltammetry (DPV). Figure 1a., illustrates the detection of pure catechol and figure 1b., illustrates the detection of pure AA at high concentrations (0.05 M) with a CNT-P3HT modified carbon electrode. Figure 1c., illustrates the successful detection of catechol and AA (without the need of prior separation) with the CNT-P3HT electrode where a bare carbon electrode would not successfully detect the catechol and AA simultaneously. AA (Vitamic C) is a common interference that has been found to be 5 times the amount ratio to the concentration of catechol for real-world samples. Due to this ratio of catechol to AA, the CV cannot detect a mixture of AA+Catechol successfully. Therefore, the DPV technique was utilized where the higher concentrations of AA (5 times AA) common interference, to the catechol were studied to analyze the novel CNT-P3HT electrode to detect the two chemicals without the need of prior separation, Figure 2.

Figure 3 illustrates the successful growth of the CNT-P3HT material by the Scanning Electron Microscope-Energy Dispersive X-Ray Analysis (SEM-EDX) illustrating the presence of C and S.

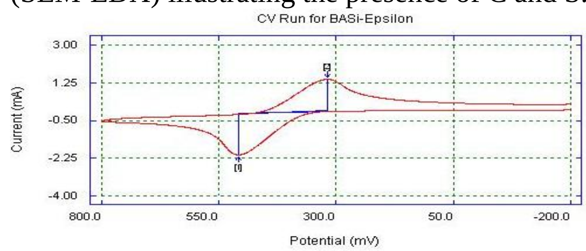

Figure 1a. CV of CNT-P3HT electrode in detection of 0.05M catechol

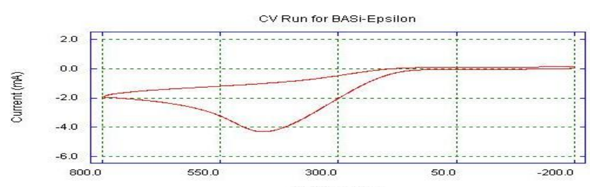

Figure 1b. CV of CNT-P3HT electrode in the detection of 0.05 M AA

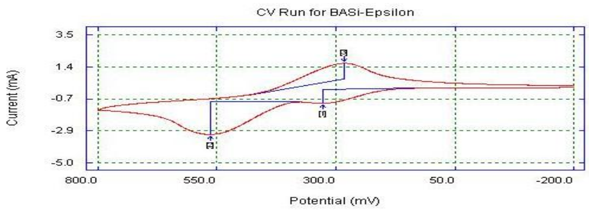

Figure 1c. CV of CNT-P3HT electrode in the detection of 0.05 M catechol and 0.05 M AA.

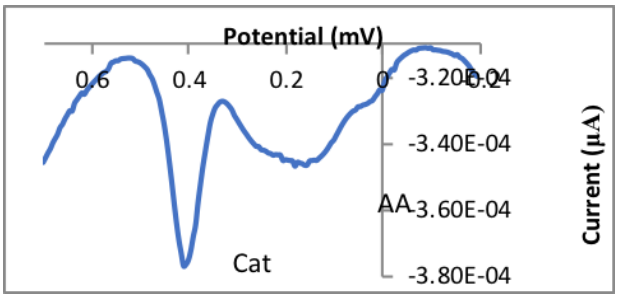

Figure 2. DPV of simultaneous detection of 0.1 mM catechol + 5mM AA at CNT-P3HT electrode.

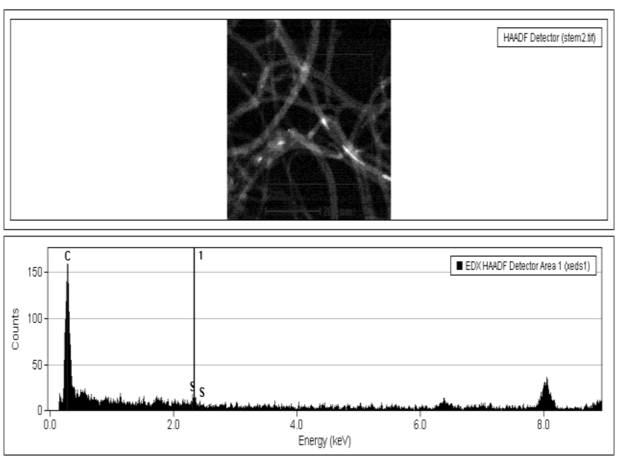

Figure 3. The Scanning Electron Microscope-Energy Dispersive X-Ray Analysis of CNT-P3HT electrode

In Figure 4, the SWASV of 10 ppm lead and 10 ppm of cadmium mixture was successfully detected without the need of prior separation with the CNT-PSS-Ag. The lead is approximately at -500 mV and the cadmium peak at -700 mV.

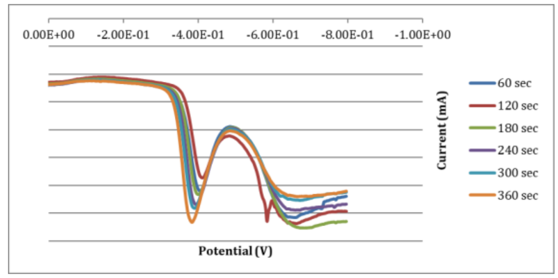

Figure 4. SWASV of CNT-PSS-Ag in the detection of 10 ppm lead and 10 ppm cadmium

4. CONCLUSION

This paper shares the undergraduate students learning novel electrochemistry techniques such as CV, DPV and SWASV to detect carcinogenic and heavy metals with the use of a novel MWCNT with polymer (PSS) which exhibited a successful response integrated with a Ag nanoparticle. The students were engaged by studying the oxidation reactions that related to chemicals involved in everyday real-world environmental concerns to detect and analyze rapidly. This lab has allowed students to fabricate a more selective /electrocatalytic working MWCNT-polymer /nanoparticle electrode surface without the need of prior separation with the use of electrochemistry. The collaboration with industry and universities such as University of Central Florida-Nano Science Center and industrial partners have allowed our students to develop real-world sensors (MWCNT) that may meet the need of our planet's seven billion people to detect the environmental hazards such as lead, cadmium and 1,2-dihydroxybenzenes. The students that participated in the problem based electrochemistry lab setting have shown increased content gains with pre-test scores of 15.6% and post-test scores of 77.0 % giving a normalized gain of 0.727, where normalized gains greater than 0.7 signify high content gain. Chemistry classes that are cookbook/lecture based have been found to typically show low gains of 0.23 for traditional course work. This collaborative research experience has assisted our science education majors to succeed on the OAE test as well. From the years of 2017- 2019, our pre-service teacher participants in IBL chemistry modules had a 91.7% pass rate in the content assessment. These IBL modules are problem-based with critical thinking which have seem to play an increasing role to assist our pre-service teachers to meet the state and national standards and pass the OAE with overall success.

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