

Integration of teaching topics to enhance undergraduate research experience in Synchrotron based X-ray absorption EXAFS for corrosion study and Electroencephalography EEG application projects

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Abstract

The hypothesis of integrating teaching topics to enhance undergraduate research experience in Synchrotron based X-ray absorption EXAFS for corrosion study and Electroencephalography EEG application project has been studied. The procedures are (1) using electrostatic interaction of a triangular charge system to illustrate the potential energy environment in EXAFS, and (2) using electrostatics with dipole noise to teach the EEG signal source. The Excel spreadsheet calculation environment further enhances the student calculation capability. The comparison to the project pedagogy in space weather, bio-molecular electrostatics, and noisy data analysis in gravitational wave detection are discussed. The learning assessment rubric of Highly Competent, Competent, and Needs Improvement versus Participant Deliverables was used. An improvement was observed in the grades of discussion sections of student posters and the written interpretation of numerical calculations in the related student submitted manuscripts. Recruitment of lower GPA students into high impact projects is discussed.

I. Introduction

Queensborough Community College embraces high-impact practices. The associated webpage has the following descriptions: (1) High Impact Practices are instructional modalities that facilitate students learning skills and competencies, not just content or information. (2) Working with faculty, students participate in current research from all of the sciences, through research courses and grant-funded undergraduate research programs, some of which provide summer stipends and opportunities for independent research. Students work on projects, attend seminars and are encouraged to present or publish their results ¹. Our physics department provides physics courses and undergraduate research projects for engineering and technology students. The hypothesis of integrating teaching topics to enhance undergraduate research experience in Synchrotron based X-ray absorption EXAFS for corrosion study and Electroencephalography EEG application project has been studied.

II. Electrostatics analogy of EXAFS Local Energy Environment

Given a sample, the EXAFS technique can be used to study the local environment of an element inside the sample. For example, the oxidation state of Fe, important for corrosion studies^{2,3}, can be deduced from EXAFS data. The electron energy levels of an atom are affected by the local electric potential energy with contributions from the nearby atoms. A typical Synchrotron-based X-ray Absorption data plot would show absorption at energy beyond the regular K-edge (or L-edge). When the incoming X-ray energy exceeds the K-edge energy, the remaining energy would be given to the released photoelectrons. Furthermore, a photoelectron would show resonance when partially confined by the potential imposed by the neighboring atoms. Although the quantum resonance for the superposition of the reflected electron wave and the out-going electron wave has no analogy in the first year physics courses, the vibrating string experiment probing the wave velocity as proportional to string tension divided by mass per unit length and also the product of frequency and wavelength would offer a working analogy where the allowed wavelength depend on the given confinement size. The formula $f_n = n/2L * \sqrt{\text{tension/mass per unit length}}$ for the n-mode excitation clearly shows the wave resonance condition dependence on L, the string length or confinement size.

The potential energy of a single atom is simply the Coulomb potential energy caused by its nucleus with a small correction caused by its nearby atoms. A potential energy analogy has been used when teaching electrostatics in the second course of the first year physics sequence. Conceptually the analogy is relying on the electrostatic interaction of a 2-D triangular charge system to illustrate that the potential energy along one direction is similar to the potential energy found in EXAFS condition. Excel calculation result is easy for visualization and the learning assessment in second semester calculus physics can be performed using the following electrostatic interaction question.

Question: Three negative 2-milligram -7-nano-Coulomb identical charges were positioned rigidly on the vertices of a 4-m equilateral triangle. The charge locations are (0, 0), (4*cos(30), 4*sin(30), and (4*cos(-30), 4*sin(-30)). A positive 2-milligram 2-nC charge from infinity, in the same 2-Dim plane, was pulled into the center of the triangle and then the 2-nC would overshoot due to momentum. Find the 2-nC speed when it reached the center of the triangle. Do include a graph and some numerical information in the explanation. The 2-nC charge could be released from rest at (centroid + 0.3 m, 0), explain what would happen.

A plot of the potential along the x-axis going through the centroid of the equilateral triangle would show a small potential well near the centroid and a deep potential well when moving towards the charge located at (0,0). This graph illustrates the essential features of the EXAFS potential energy where the Coulomb potential of an individual atom would be modified by the nearby local atoms.

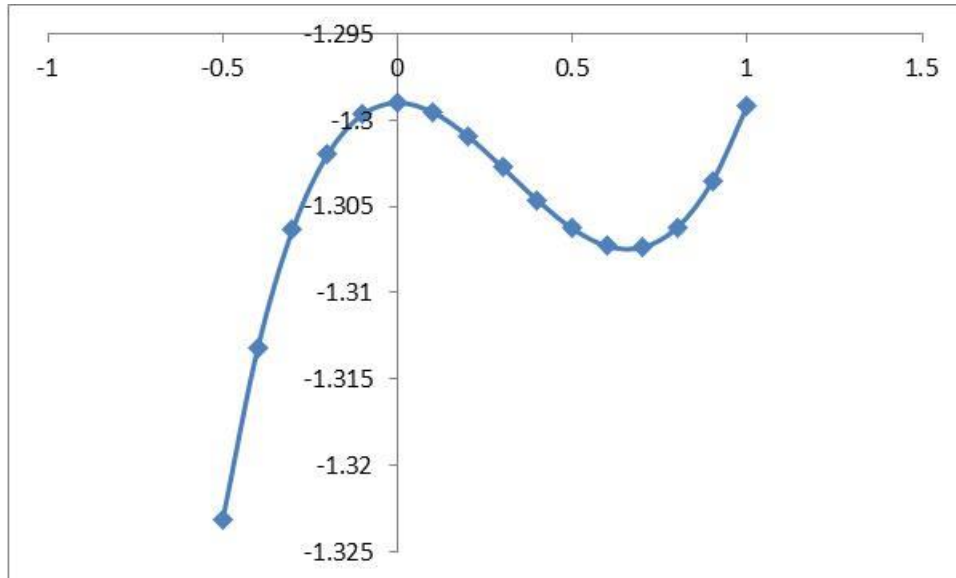


Figure 1: Potential along the x-axis measured from the centroid of the given triangular charge configuration. The y-axis represents the potential energy value (arbitrary unit)

III. EEG Technology based Client-Company Simulation

The electrical signals in EEG or local field potential are coming from the electrostatics dipole sources under the scalp and there are free access references on the web ^{4,5}. Teaching ready examples at elementary integral knowledge in electrostatics are displayed in Reference 5. The examples include (1) Electrode Impedance with Ideal Leads and Voltmeter, (2) Resistive Component of External Impedance for Spherical Conductor in an Infinite Resistive Medium, (3) Capacitive Component of Impedance for Spherical Conductor in an Infinite Resistive Medium, (4) Infinite Cylindrical Conductor in a Finite Resistive Medium, (5) Capacitance of Neuron Membrane, (6) Solution to the Diffusion Equation, (7) The Electrical Potential Arising From Diffusion of Cations and Anions Together, (8) The Electrical Potential Arising From A Current Dipole, and (9) The Electrical Potential Above A Coherent Layer of Pyramidal Neurons. A large population of oscillating dipoles not in synchronization could be modeled as bio cells with noises. The time average with noises would give a signal in the order of \sqrt{N} with N being the number of parallel dipoles ⁶.

Building an integrand is an important topic in teaching electrostatics and there are numerous education research papers on how to improve the student deliverables ^{7,8,9}. One of our favorite examples is to ask the students to build an integrand to find the off-center E-field inside a ring given a charge density. The solution for the uniform charge density has been posted on YouTube recently with funding from The Hertz Foundation on the concept of School-Yourself ^{10,11}. Although our department only has EEG data collection capability, the magnetism integral

examples applicable for the understanding of Magnetoencephalography MEG have been taught as well for advanced project interested students¹².

IV. Discussion

Our department also has space weather and bio- molecular electrostatics projects. Space weather project pedagogy requires an independent research class outside of the regular calculus physics sequence and the modern physics class because of its use of statistics for geomagnetic storm classification and magnetic reconnection complexity study. A proof of concept of magnetic reconnection is simple enough to construct. The magnetic field of two attractive bar magnets can be traced with compass such that the magnetic lines are in the correct configuration for a potential reconnection. A hanging weight via a pulley system would provide a force to prevent the two bar magnets from snapping onto each other. The force versus distance data would be summed to get the mechanical energy which is related to the snapping energy. The energy loss in the reconnection would be measured with the differences in the magnetic energy using Gauss-meter data. The experimental set up has been posted on our department website¹³. But the next step of plasma with EM radiation coupled onto fluid mechanics in magneto-hydrodynamics is insurmountable for students at a community college. Therefore our space weather project teaching focuses more on the statistical characteristics. The projects in bio- electrostatics can be incorporated with affective learning for pre-med and health science majors; but the pedagogy is different since the teaching materials are scattered among the research articles as far as we know. Electrostatic bio- molecule structure examples are available for simple modeling at calculus physics level^{14, 15, 16}.

The recent detection of gravitational wave had stirred up excitement among some students. Our students can only read popular science writing websites and ask questions. One of the questions came from the following statement from Quanta Magazine: “Because the whole reason you can detect the signal is that it has this characteristic sweep, and you filter the data against it. But you can only filter if you know what the signal looks like, and since you’ve never seen it before, you can only know what it looks like if the theorists tell you”¹⁷. A teaching explanation can be generated using Excel platform with Visual Basic Engine where a known small sinusoidal signal is buried inside a large white random noise. Now the total signal is less than random and its correlated randomness can be characterized by the Higuchi fractal dimension method¹⁸. Subtraction of the known small sinusoidal signal would then yield a random signal having a fractal dimension of two. This is one way to explain the importance of supercomputer simulation studied by theorists because only then the experimentalists would know what to filter off in the noisy data. In other words, once the gravitation wave chirp is known, the data recovery would be straight forward although the waiting time for the next event is unknown. This kind of simulation projects also requires a different pedagogy from that of a regular calculus physics sequence. The recruitment of lower GPA students into high impact projects without calculus

physics preparation into this kind of noisy data analysis has been conducted and about 10 technology students had participated in the last 5 years.

A project has several aspects in terms of learning in the cognitive, affective and psychomotor domains. The cognitive learning is not easy because it involves deeper understanding of the physics and technology. We are supposed to teach students to do high impact research projects. A student is expected to use reasoning to recognize facts from information, use skill to do data collection and analysis, and use critical thinking to link the result to the current literature. The student performance in project cognitive learning has been assessed as satisfactory (score above 75% using highly competent =1, competent = 0.8 and needs improvement = 0.6). The rubric guideline is displayed in Table 1. An improvement was observed in the grades of discussion sections of student posters and the written interpretation of numerical calculations in the related student submitted manuscripts. We believe that the learning assessment rubric design can be extended from physics projects to engineering projects with some modifications.

Participant Deliverable	Highly Competent	Competent	Needs Improvement
Recognition of facts from information (20%)	Writing showed correct reasoning to recognize of facts from information	Writing showed reasoning to recognize of facts from information but made one mistake	Writing showed poor reasoning to recognize of facts from information and made more than one mistake
Data collection skill (20%)	Collected the data properly with low noise with the given procedure	Collected the data but with more noise such that S/N is still >1	Collected the data with noise such that S/N <1 and the data became useless for analysis
Data analysis skill (20%)	Correctly computed the analysis algorithm with no mistakes	Correctly computed the analysis algorithm with mistakes that were fixable upon inspection	Incorrectly computed the analysis algorithm
Critical thinking linking the result to the current literature (30%)	Utilized cause and effect inquiry in critical thinking to link result to the current literature	Utilized cause and effect inquiry in critical thinking to link result to the current literature but made one mistake	Utilized cause and effect inquiry in critical thinking to link result to the current literature but made more than one mistake
Manuscript Abstract writing (10%)	Included results and conclusions correctly	Included results and conclusions correctly but made one mistake	Included results and conclusions correctly but made more than one mistake

Table 1: Project Cognitive Learning Assessment Rubric. The participants are students. Scoring could be performed when assigning Highly Competent = 1, Competent = 0.8 and Needs Improvement = 0.6.

The affective learning is relatively easy because the project is not a required activity and it is the student motivation that originated the project activity. The psychomotor learning is achievable because muscle memory could provide some reasonable control of delicate knobs in sensitive un-automated equipment upon training with patience. Collegiality correctly understood and expressed as helping each other getting things done instead of just saying nice greetings, sharing donuts, etc. is a valuable skill. Our community college is part of the City University of New York System. The research integrity seminar and its activities as required by CUNY is another

impressive experience for students to put on their resumes. Another CUNY requirement of taking an online course on the prevention of work place violence is another remarkable opportunity for project students to learn.

V. Conclusions

Using teaching topics to enhance undergraduate research experience in EXAFS for corrosion study and EEG application project has been studied. The comparison to the project pedagogy in space weather, bio-molecular electrostatics, and noisy data analysis in gravitational wave detection are highlighted. The learning assessment rubric was used to show an improvement in the grades of discussion sections of students. Future studies could include the pedagogy of using university research project videos with instructor questioning at specific video frames.

VI. Acknowledgements

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