Application of Engineering Taxonomy for Assessing Problem-Based Learning in Underrepresented Groups

Dr. Leanne Petry, Central State University

Dr. Leanne Petry is an Assistant Professor in the College of Science and Engineering at Central State University. Her expertise is in analytical and materials characterization techniques, including microscopy, spectroscopy, chromatography, and electrochemistry. Her research interests include oxidation-reduction reactions at the surface of electrodes for sensor applications, corrosion mechanisms of materials, as well as their electrochemical degradation. She has incorporated problem-based learning into her lectures, laboratories, and outreach activities to engage students and the community in the STEM education process.

Dr. Morris M. Girgis, Central State University

Morris Girgis is a professor at Central State University. He teaches undergraduate courses in manufacturing engineering. He received his Ph.D. in mechanical engineering from Hannover University, Germany. His current research in engineering education focuses on developing and implementing new educational tools and approaches to enhance teaching, learning and assessment at the course and curriculum levels.

Application of Engineering Taxonomy for Assessing Problem Based Learning in Underrepresented Groups

ABSTRACT

Problem based active learning is an effective way to engage undergraduate STEM students and enhance their critical thinking skills, especially in minority learners. Using a three-tiered engineering taxonomy for cognitive learning, a semester long multidisciplinary project was assessed as part of an upper level Instrumental Analysis course at Central State University (CSU), an 1890 Land Grant Institution located in Wilberforce, Ohio. The Problem Based Learning (PBL) experience focused on materials degradation and was designed to give STEM majors an open ended opportunity for hands-on, student driven discovery by experimenting with various analytical techniques to solve a real world problem in the field of corrosion. The materials were artificially degraded so that the effects of exposure time and service environment impacted the corrosion properties of the sample. The PBL project was structured to assist undergraduate students in learning how materials degrade with time, appreciating how environment can influence degradation, as well as identifying alternative career paths for the purpose of employment or pursuit of graduate programs such as in the field of corrosion or failure analysis. The project setup required the creation of a scenario in which the student was called upon by the court system to provide expert testimony in support of a mock case related to the degradation and in service failure of a manufactured material. The overarching question for the student to answer for the mock court and mock jury was why the material degraded and eventually failed. The degraded material provided the sample for analysis and characterization. Individual student problem solving required tier one prerequisite fundamental knowledge in STEM disciplines in order to identify a strategic plan for root cause analysis of a failed material. Tier two application of this knowledge enabled systematic characterization of the failed substance to be conducted. Lastly, advanced knowledge and analytical skills completed the three tier scaffolding necessary to guide the student working on the PBL project. The student's final written report and expert testimony presented to the mock court provided evidence based data to support their conclusions and a means to assess conceptual understanding in this PBL scenario. Student reflection and instructor feedback in addition to the three tiered framework rubric facilitated assessment of the student cognitive learning process. Additionally, it was observed for a seven contact hour a week course that students were engaged in the project between 10-12 hours/week gaining more practical, hands-on experience in engineering materials and their methods of deterioration. As a result of this experiential learning, the students involved in PBL projects (as compared to semesters in which students did not use PBL) produced better quality work as demonstrated through increased time on task, improved oral presentations and better quality discussions of data as presented in final written reports.

Introduction

For more than 20 years, chemistry faculty have been proponents of Problem-Based Learning (PBL) as a means to bridge the gap between what students learn in the classroom and what students' experience in the laboratory.[1] Traditional assessment measures such as formative feedback on problem sets or draft laboratory reports enable students to improve learning prior to summative assessments such as unit, midterm or final exams.[2] However, students who perform well on exams may not possess the skills required to excel in the workforce environment such as a chemical production laboratory or manufacturing engineering plant.[3] Senior undergraduate research or capstone projects are usually the first experience college students have with experimental or engineering design processes.[4] Incorporation of authentic PBL methods to teach engineering principles with uncertain investigation outcomes to a broader group of underrepresented students (i.e. minorities, women) prior to research based coursework enables them to make connections between instruction and the real world earlier and to gain a deeper understanding of their course content.[5-9]

Problem Based Learning Design and Objectives
The engineering practice of using models to simulate systems and interactions as a means to construct explanations and design solutions based on valid and reliable evidence is directly relatable to the instrumental analysis laboratory using the 5E approach of engage, explore, explain, elaborate, and evaluate.[10] In order to assess the conceptual and procedural knowledge and skills developed in the instrumental laboratory using the PBL approach, a three-tiered engineering taxonomy developed by M . Girgis in 2010[7], and refined in 2011[8] and 2015[9] was applied to a real world problem in the field of corrosion[11] with additional evaluation conducted using institutional rubrics adapted from the Association of American Colleges and Universities (AACU) VALUE rubrics at http://www.aacu.org/value-rubrics to identify the student learning outcomes for critical thinking and written communication at both the course and institutional level[12-13] based upon evidence presented to differentiate between cause and correlation and to make claims about specific causes and effects.

PBL Project Title: Problem Based Learning Approach for the Chemical Analysis of a Degraded Material: Corrosion Science in the Instrumental Analysis Laboratory

PBL Overview: This laboratory project experiment examines real world materials that have reached the end of their service life design or failed in service during operation. The degraded material, provided by a majority serving institutional partner, served as the sample for the final chemical analysis project. The goal of this PBL experience was to give STEM majors an open ended opportunity for hands-on, student driven discovery by experimenting with various analytical techniques and their limitations to solve a real world problem in the field of corrosion. The effects of exposure time and service environment were known to the instructor from the existing partnership[11] and were found to impact the corrosion properties of the given material. Therefore, the objectives of the PBL project were structured to assist the undergraduate students in learning how materials degrade with time, appreciate how environment can influence degradation, and identify alternative career paths such as in the field of corrosion for root cause investigation and instrumental analysis.

PBL Objectives: The primary objectives of this project were to (1) develop a method to examine material degradation, (2) assess and validate corrosion damage by comparing and/or contrasting results from multiple analyses, and (3) conclude whether or not the mechanism of corrosion was due to environmental ingress (i.e. acetate, formate, chloride or glycol based deicers, sea salt, industrial pollutants, etc.), inappropriate material substitution or mismatch (i.e. alloy composition, equilibrium potential, pitting potential). In accordance with the findings, students made inferences and formulated a plan to repair or remove the damage to return the material back to service and provide a service to the local corrosion community.

Curriculum Development and Pedagogy

Defined PBL scenario: Individual students working as apprentices in a failure analysis laboratory were called by the defense (or prosecution) to provide expert testimony in support of (or against) a court case related to a report written by the student apprentice on the degradation and in service failure of a manufactured material. The overarching question to answer for the court and jury was why the material degraded and eventually failed. The written report and expert testimony provided was based on evidentiary analytical data which supported the apprentice's conclusion(s) in this PBL scenario.

Identified background: Students were to search the scientific literature to find a published procedure suitable for the analysis of the desired components of the sample(s). Students were required to be able to accomplish the procedure with four (4) of the instruments that were available in the instrumental analysis laboratory. Students needed at least two (2) published, peer-reviewed literature articles for each technique intended for use as a point of reference. Copies of the journal articles were provided with summarized background information on each technique along with a defense for the decision made for the choice of method (as assessed in the CSU Critical Thinking Value Rubric).

Proposed Approach: Student apprentices were to build the proposed framework for their individual testimony from an instrument based tool box to use as a road map to the get to the root cause of the PBL scenario. They needed to identify the key skills and competencies required to conduct their analyses, such as research ethics, content knowledge and informational literacy skills; practical and problem-solving skills; technical approach and application skills; interpretive analysis, synthesis, and evaluation skills; as well as associated skills related to business and financial skills plus written and oral communication skills. Laboratory safety and hazardous waste disposal were also to be considered and discussed. Additionally, they were required to make a preliminary list of the ancillary supplies needed along with the cost to perform the analyses by each of the techniques chosen (i.e. Students needed to go to the manufacturers' websites (i.e. www.sigma-alrich.com) and look up reagents, solvents, consumable products, specialized glassware, etc.) to gain a working knowledge of the cost of consumable materials and supplies. A formatted supply list was to be submitted with their proposed methodology to account for the cost of doing the analysis with enough materials and supplies to perform the experiment 3 times (i.e. in triplicate). Students received formative feedback on their proposed approach for each instrumental technique.

Detailed Examination: In this section of the PBL experience, students examined the material surface at multiple locations (in the region of degradation and adjacent to the region of degradation) with an optical or digital microscope. Students photographed the sample at different magnifications to convey the type of damage noted as a result of this examination and denoted a physical size to the sample as well as areas of interest. Understanding how scale and proportion on one scale relates to a model at another scale informed considerations students made about sample considerations such as: representative sampling, sample handling, sample dissolution, sample preparation, and sample size for each analytical technique. These considerations were intended to answer the following questions:

What material can it be?

What are the possible products of degradation?

What is the level of agreement among the different analytical techniques?
What mitigating factors may be responsible for any discrepancies?
Is the root cause a plausible and defendable explanation (questions/answers)?

PBL Timeline: The first three laboratory days of the PBL Project were devoted to planning. Student apprentices needed to plan not only what to do and how to do it, but also how to divide the work for maximum productivity and efficiency as only one apprentice was able to use a given piece of instrumentation at a time. At the end of the third week, students submitted an experimental design proposal. In the proposal, it was to be specified what the variable(s) investigated was with each of the four instrumental techniques and details of the methods and procedures used for incorporating the feedback received from the literature review summary. Various aspects of the experimental design, theoretical modeling, and primary mode of documentation for the PBL were to be identified and why it was important to the analysis process. Student apprentices were given exclusive responsibility for all parts of the project, including sample chain of custody and were expected be productive, contribute significantly, and understand all aspects of analysis required for the project. The experimental design proposal was the starting point for experiments.

Data Collection and Program Evaluation

Once experiments were underway, students needed to adjust and refine their procedures and hypotheses since instrumental analyses rarely worked the first time exactly as planned. Problems occurred and new questions arose. Students modified their experiments to solve the problems and/or answer those questions. This process was repeated multiple times over the course of the PBL and semester and cemented the process of engineering design in the mind of the students.

PBL Reporting: Students were required to keep good records on the development of the experimental controls, procedures, and validation of the experimental procedure in a bound laboratory notebook. Written step by step instructions, including calculations of concentration of analyte in the sample along with uncertainty for how standards and samples were prepared in addition to what procedure was used for measuring and reporting uncertainty in the measurements were to be noted. This information was to be included in the final report, which served as the basis for their expert testimony in this scenario, along with calibration plots and results from samples analyses for each technique. A PowerPoint presentation (the expert testimony during which other students played the roles of attorneys, witnesses, judges, and jurors while engaging in this class) summarizing results from all techniques was also required and provided the class (i.e. the jury) a chance to share ideas, ask questions, and compare results. In the report and presentation, students were to discuss the component of the sample analyzed and provide a brief explanation of the experimental design developed discussing the detection limits of the method, the data collected related to the control experiment, what experimental difficulties were encountered and what areas need improvement. Reports and presentations were graded on completeness, quality of the graphs (including the formatting), and the quality of discussion presented. In the next iteration of the PBL, student apprentices will be required to receive feedback by outside legal consultation (details of which are in progress).

PBL Assessment: Using the three-tiered engineering taxonomy and rubric instrument developed by Girgis, the student overall conceptual knowledge and PBL experience was assessed as foundational, intermediate or advanced tier levels.[7] Institutional rubrics for assessing critical thinking and written communication were also used to evaluate final reports and presentations (the expert testimony). Critical thinking focus areas were: explanation of issues, evidence for selecting and using information to investigate a point of view or conclusion, influence of context and assumptions, student's position and perspective/thesis/hypothesis, as well as conclusions and related outcomes or implications and consequences. Written communication outcomes assessed included: context and purpose for writing which includes considerations of audience, purpose, and the circumstances surrounding the writing task(s), content development, genre and disciplinary conventions such as formal and informal rules inherent in the expectations for scientific and technical writing as well as sources and evidence, and finally control of syntax and mechanics.

Table 1. *Summary of Assessment Results*

Assessment Rubric	Ranking	Outcomes
Engineering Taxonomy[7]	Tier III (Step IV of VII)	Working Knowledge to Solve Multiple Concepts
Critical Thinking[13]	Capstone (Score of 4 out of 4)	Working Knowledge to Identify Problem and State Outcomes that are Logical Based on Use of Evidence to Support Conclusions
Written Communication[12]	Capstone (Score of 4 out of 4)	Working Knowledge to Develop Context using Content, Syntax and Writing Mechanics Appropriate to Discipline

Table 1 summarizes assessment results. Overall conclusions and related outcomes (consequences and implications) presented by students for the PBL scenario were logical and reflected student’s informed evaluation and ability to place evidence and perspectives discussed in priority order. This working knowledge to thoroughly (systematically and methodically) analyze one’s own and others' assumptions and carefully evaluate the relevance of contexts when presenting a position places their experience at the bottom rung of the Level III advanced tier for problem solving in terms of engineering taxonomy. This assessment is corroborated by the value rubrics for critical thinking and written communication which scores this ability as Capstone. However, when the viewpoints of experts were questioned thoroughly upon cross-examination, it was noted that the student apprentices positions were limited and primarily in the Level II intermediate tier and lacked in depth knowledge necessary to make specific inferences about the data. Apprentices were still emerging in the development of critical thinking and persuasive speaking and writing skills as the ability to comprehensively deliver and develop all relevant information necessary for full understanding of the PBL experience by the jury was lacking for complete interpretation and synthesis of data.

Summary

Changing the course format from a traditional lecture (3 contact hours/week) with pre-defined laboratory experiment outcomes (4 contact hours/week) to a PBL approach motivated students to spend more time in the instrumental laboratory (i.e. greater than 10 hours/week), become more invested in the course content and to develop higher order thinking and analytical skills. As a result of being introduced to this new learning environment, students were engaged, connected different types of information (i.e. math, chemistry, physics), and transferred ideas to this learning experience which in turn improved the student learning outcomes for critical thinking and written communication at both the course and institutional level, as evidenced in their final project presentation and report.

Acknowledgements
This curriculum development effort was made possible, in part, by the test sample support provided by Dr. Douglas C. Hansen from the University of Dayton Research Institute following the conclusion of work originally sponsored by the SERDP-ESTCP Program under contract FA8601-06-D-0013. Additionally, the guidance of Dr. Thomas J. Wenzel (Bates College) and Dr. Cynthia K. Larive (University of California, Riverside) plus the financial support of the National Science Foundation (NSF DUE 1118600) that made possible participation in workshops at Spelman College (2014) and Indiana University (2016) on the development of active learning exercises for use in the analytical chemistry curriculum is appreciated. Lastly, any opinions, findings, and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the program sponsor(s) or its principal investigator(s).

Bibliography

1. Thomas J. Wenzel, "A New Approach to Undergraduate Analytical Chemistry", Analytical Chemistry (1995), pp. 470A-475A.
2. Thomas J. Wenzel, "Defining Course Goals", Analytical Chemistry (2000), pp. 659A-661A.
3. Thomas J. Wenzel, "The Limits of Written Tests", Analytical Chemistry (2001), pp. 43A-44A.
4. Thomas J. Wenzel, "Undergraduate Research: A Capstone Learning Experience", Analytical Chemistry (2000), pp. 547A-549A.
5. Kent J. Crippen, Treavor H. Boyer, Maria Korolev, Trisha de Torres, Phil J. Brucat, and Chang-Yu Wu, "Transforming Discussion in General Chemistry With Authentic Experiences for Engineering Students", Journal of College Science Teaching (2016), Vol. 45, No. 5, pp. 75-83.
6. Henry A. Kobulnicky and Daniel A. Dale, "A Community Mentoring Model for STEM Undergraduate Research Experiences", Journal of College Science Teaching (2016), Vol. 45, No. 6, pp. 17-23.
7. Morris Girgis, "A New Engineering Taxonomy For Assessing Conceptual And Problem Solving Competencies," 2010 ASEE Annual Conference and Exposition, Louisville, KY, June 2010 Paper ID # AC 2010-1793.
8. Morris Girgis, "An Active Learning Environment for Enriching Mathematical, Conceptual, and Problem-Solving Competencies," 2011 ASEE Annual Conference and Exposition, Vancouver, BC, June 2011 Paper ID # AC 2011-2038.
9. Morris Girgis, "A Scaffolding Case Study for Teaching Engineering Problem Solving to Underrepresented Minorities," 2015 ASEE Annual Conference and Exposition, Seattle, WA, June 2015 Paper ID # 14124A.
10. Carol Robertson, "Modeling DNA: Understanding the Structure of DNA through Models and Motion", The Science Teacher (Summer 2016), pp. 26-32.
11. Leanne Petry and Douglas C. Hansen, "A Comparative Study of Two Coating Systems Exposed for Two Years in the Field and in Accelerated Atmospheric Corrosion Chamber Environments", CORROSION (2016), Vol. 72, No. 11, pp. 1385-1396.
12. Central State University Assessment Rubric for Written Commination adapted from the Association of American Colleges and Universities (AACU) VALUE rubrics at http://www.aacu.org/value-rubrics.
13. Central State University Assessment Rubric for Critical Thinking adapted from the Association of American Colleges and Universities (AACU) VALUE rubrics at http://www.aacu.org/value-rubrics.