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Exploring the Effectiveness of an Interdisciplinary Corrosion Engineering Module in High School Courses (Evaluation)

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The purpose of this work was to evaluate the effectiveness of a corrosion engineering module in high school science courses. The intent of the module was to present basic concepts on corrosion engineering and then reinforce student learning via a project-based learning assignment on the corrosion of winter maintenance vehicles in the State of Ohio. The module's educational objectives were to (1) increase knowledge among high school students about the factors associated with corrosion, specifically vehicular corrosion, (2) increase student understanding of engineering principles behind corrosion prevention and mitigation, and (3) engage students in multiple interactive, hands-on activities to reinforce their learning. Pre- and post- assessments were administered to (1) determine if an engineering module would allow students to develop a more complex understanding of corrosion engineering problems and higher levels of corrosion science knowledge, (2) assess whether students would develop more complex reasoning towards corrosion prevention and mitigation through the engineering module, and (3) evaluate the students ability to apply engineering and design principles. The long-term goals of the module were to improve societal awareness of the safety and economic issues of corrosion and increase participation in STEM fields. The present study assessed the ability of the module to achieve the short-term education objectives.

Overall, students (n=69) showed statistically significant improvement in complex reasoning on design questions ($p<0.02$) and greater content knowledge ($p=0.03$) after the implementation of a corrosion engineering module. This research indicates the effectiveness of our corrosion-engineering module in enhancing student learning and supports its inclusion in high school classrooms.

Introduction

In order to continue the United States' role in the global economy, there is a need to strengthen our student's skills in the fields of science, technology, engineering, and mathematics (STEM NRC, 2009; Chen, 2009; Kuenzi, 2008). Corrosion, the degradation of a material's properties as a result of its interaction with a given environment, plays a critical role in determining the performance, safety, and cost of engineered products and systems. However, according to a National Research Council study "corrosion as a subject taught in our education system is at risk because it is almost nonexistent. (NRC, 2009)" In light of the rapid rate of infrastructure degradation, the study listed several strategies for corrosion prevention including increasing awareness of the large cost of corrosion, changing misconception that nothing can be done about corrosion, improving corrosion education and training, improving design practices, and advancing corrosion technology through research. In short, creating a pipeline of knowledgeable corrosion scientists, engineers, and technologists was determined to be the most effective method for developing a competitive workforce in the field of corrosion. While these are important guidelines that can help educators to structure lessons that develop a greater understanding of corrosion and its effects on society, questions remain about how to translate the topic into classroom instruction and the subsequent impact on student learning, specifically through the use of engineering and applied science modules.

Education and outreach programs are one way to increase public knowledge and understanding on the safety and economic issues associated with corrosion It has been shown that introducing students to STEM topics through project-based learning (PBL) in K12 increases their interest in the topic, promotes curiosity, and increases the likelihood of selecting and graduating with a STEM major (Andrews, Bufford, Banks, Curry, & Curry, 2014; Barrett, Moran, & Woods, 2014; Sanders, 2009; Wuang, 2013; Hall, 2016). Students participating in project-based learning are also more likely to retain the content knowledge acquired, compared to traditional lecture-based techniques (Dargham, 2015). In fact, over the past decade and a half, millions of K12 students have experienced engineering education integrated into the regular school curriculum (Dori, 2009, 2009) including numerous studies on integrating PBL into engineering education (Fink, 1999, Frank, 2003, Martinez-Mones, 2005, Macias-Guarasa, 2006, Eskrootchi, 2010, Kumar, 2013, Dargham, 2015). This motivated us to develop a corrosion engineering module in order to engage students in the development of their problem-solving skills by applying engineering, science, math and technology to solve an ill-defined problem. Through the use of an engineering module, students are exposed to unstructured problems like those they will experience in the real world and can learn to develop solutions based on scientific, economic, and societal data.

In an effort to address the need for a high quality K12 corrosion engineering curricula, we developed and implemented the Corrosion Engineering Curriculum (CEC) based on the anticipated problem map shown in Figure 1. The CEC modules apply mathematics, material science, electro-chemical engineering, and engineering design concepts to corrosion issues associated vehicular corrosion (e.g. salt trucks). The CEC lessons also aim to inform students about careers in corrosion engineering. Throughout the course of this research, the module was

implemented at a local high school in different science and engineering courses between 2014-2016.

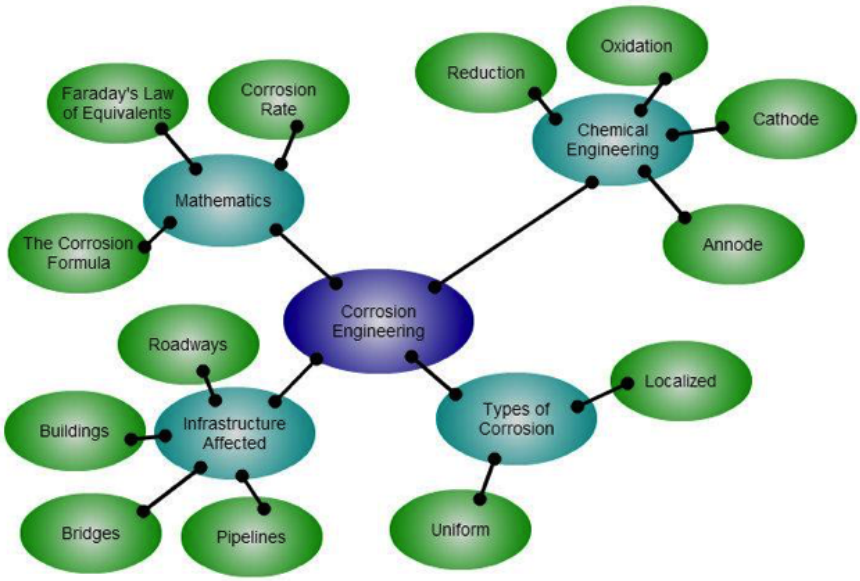

Figure 1: Anticipated problem map for the corrosion engineering module

Research Questions

The purpose of this study was to investigate if participation in the CEC changed the student's knowledge about corrosion engineering, engineering design, and complex reasoning skills.

1) To what extent did student's knowledge of corrosion engineering change as a result of participation in CEC lessons
2) To what extent did student's complex reasoning skills change through participation in CEC lessons
3) To what extent did student's ability to apply engineering design principles change as a result of participation in CEC lessons

Literature Review

K12 Engineering Education

Over the past few years, the role of STEM education has evolved from simply providing students with content knowledge and understanding to promoting engineering-based curriculum. Widespread integration of engineering into K12 curricula has faced many challenges including the large scale professional development of the current K12 teachers, integration of engineering into previously developed school curricula, educational policies influenced by standardized testing, and the lack of teacher certification and teacher preparation programs in engineering (Katehi, 2009). With the adoption of the NGSS and the *Framework for K-12 Science Education*

(NRC, 2012, NGSS, 2013), engineering is now an integral part of K12 STEM education. In particular, engineering education is expected to "(1) focus on design and problem solving; (2) incorporate appropriate science, technology and mathematics (STEM) concepts; and (3) 'promote engineering habits of mind. (Sanders, 2009; NRC, 2012)" This has led to the development of new strategies and practices to integrate engineering curricula into traditional K12 science classrooms (Berland). However, there are few studies that evaluate the effectiveness of these innovative approaches to K12 STEM education to fully understand their impact on understanding of STEM concepts.

In order to comply with the recent reform focused on integrating engineering into more traditional science classrooms, teachers have begun applying constructivist project-based learning and higher ordered thinking into their classrooms. Higher order thinking can be defined as a complex mode of thinking often resulting in multiple solutions. According to Resnick,"higher order thinking involves uncertainty, application of multiple criteria, reflection, and self-regulation (Resnick, 1987)." In broader terms, higher order thinking can be classified using Bloom's taxonomy, overlapping with levels above comprehension (Bloom, 1956). While simple recall of information is an example of lower order cognitive thinking skills, higher order thinking skills involve analysis, evaluation, and synthesis (Zohar, 2003). Therefore, an essential goal of STEM education is to develop these higher order thinking skills in students, thereby allowing them to think critically, reason, and solve problems (Zoller, 1993, Bybee, 1994, Zohar, 2003). The connection between theory and practice is critical for students to begin to apply higher order thinking while learning.

Integration of Science and Engineering Through Project-Based Learning

Project-based learning is a constructivist approach to learning that allows students to gain a more complex understanding of materials through process-oriented engagement, based on the idea that students construct knowledge especially well during creation (Papert, 1991, Kafai, 2006). During a PBL, students investigate a real-world, meaningful problem that is posed with a "driving question". Students must respond to this question using authentic inquiry and collaborative problem solving in order to create a tangible product (Krajcik, 1994). Distinct to a PBL curriculum is the concept of "student-centered instruction" and teachers acting as "coaches," as opposed to the traditional, lecture-based delivery of material.

One of the key components of a PBL is higher-order questioning that "elicits challenges, problem solving, and analytical and/or creative thinking skills in answering the driving question (Bruce-Davis, 2014)." Therefore, PBL provides a way to create a more meaningful learning experience and a more complex understanding of the content (Blumenfeld, 1991). By application of self-regulated learning through trial-and-error, a PBL "encourages students to try multiple approaches and reflect on their successes and failures (Hall)." As a consequence, students obtain more complex reasoning skills and acquire a myriad of solutions, which has been correlated to better comprehension of materials (Dori, 2009). A study by Morrison et al suggested the problem solving algorithm and authentic inquiry approaches to learning found in PBL emphasize higher order thinking skills, suggesting the possible longevity of the PBL

framework in the K12 classroom (Morrison, 2015). In addition, it has been reported that PBL activities provide students with a non-threatening environment, without a fear of failure; therefore challenging students to continue to problem solve in order to complete the project.

Based on the description by Krajcik, effective PBL classes have the following key features: (1) PBL projects are the central component of the curriculum with teaching and student learning organized around the project; (2) Driving questions are used to motivate students to interact with "central issues, concepts, and principles of a discipline"; (3) During the project, students must engage in a "constructive investigation". Students must "investigate and transform knowledge" if a curriculum is to be considered PBL; (4) Projects must involve collaboration among the students; (5) Projects are based on "student-centered instruction". While projects are to be guided toward the important content, they should not be scripted or teacher led; (6) Students are scaffolded during the PBL to encourage them to act as more "expert thinkers" while completing their projects; (7) projects must have real-world applications and be meaningful to the students; and (8) Students must create a tangible "artifact" as their solution to the driving question (Morales, 2013). Further work by Berland described additional criteria to ensure that a project-based course is usable in a wide range of public schools with varying class size and schedule. Berland identified that during curriculum development the course must be affordable, start with an engaging unit to pique student interest without teaching "substantial content", allow for the introduction/review of the required math and science content, accommodate a "variety of physical and technological configurations," fit into a variety of classroom sizes, have electronically available course materials, and should have course materials that support teachers with a range of backgrounds (Berland, 2013).

There have been a variety of research studies on the implementation of project-based learning on engineering education. Martinez-Monez found that participation in a project-based learning curriculum on computer architecture gave students a deeper understanding of the concepts (Martinez-Mones, 2005). Eskrootchi et al determined that students involved in computer-based PBL in science and engineering programs were able to learn material at a faster rate while being more engaged in the subject matter (Eskrootchi, 2010). PBL curricula have been developed in various fields of engineering including electrical engineering (Fink, 1999, Macias-Guarasa, 2006), mechanical engineering (Frank, 2003), and chemical engineering (Dori, 2009).

Assessment of K12 Engineering Curricula

With science education reform, the assessment of learning achievements has shifted from an algorithmic, lower order thinking assessment to an assessment of higher order thinking skills (Tobin, 1990, Zohar, 2003). Previous studies have shown that assessment reinforces the learning approach adopted by a student (Marton, 1976). Simply put, if a student is tested on lower order thinking skills, they are less likely to develop a "deeper, holistic approach" to learning than students testing on higher order thinking skills. Therefore it is crucial to assess student performance by asking "significant questions, writing critical reviews, and presenting solid arguments" (Dori, 2009).

Assessment can be broken down into two broad categories: formative and summative. Summative assessment serves to evaluate student achievement, using quizzes and final exams, relative to a set of predetermined objectives (e.g. learning content). On the other hand, formative assessment is more closely aligned with the constructivist teaching approach associated with project-based learning. Formative assessment uses open-ended problems, observations, interviews, and a collection of "learning artifacts" in order to provide students with regular feedback to "regulate their own learning processes (Capraro)." By focusing on student's progress in thinking through their solutions, formative assessment empowers students to be more flexible with their knowledge. A flexible knowledge base has been shown to help students develop creative and critical thinking skills, which may help improve test-taking skills (Capraro, 2013).

During a STEM-based PBL, it is crucial to shift the focus from solely summative to formative assessment. When the assessment focus is formative, the assessment is not simply quantifying the learning process (e.g. test scores or grades). In a typical summative assessment, students are driven to perform well on tests in order to get a good grade instead of developing learning strategies. Throughout the course of a PBL, it is crucial to evaluate both the students' creative thinking skills (different solutions for different problems) and critical thinking skills (looking at events and conditions skeptically) (Birgili, 2015). Good summative assessments also show growth of the learner through the use of pre/post tests..Therefore, formative assessment is necessary. Embedded-assessments are a collection of assessment tools that can be administered at different stages of a PBL curriculum. Feedback from embedded-assessments can chart student's progress and provide educators with valuable feedback about student difficulties in order to enhance their learning. It may be that an integration of different forms of assessment (summative and formative) may have educational benefits. Previous studies have determined that integration of formative and summative assessment increased higher order thinking, the quality of learning, and students' self-confidence (Dori, 2003, Segers, 2003).

In the current study we explored the integration of summative and formative assessment modes to assess the effectiveness of our corrosion engineering curriculum at both increasing content knowledge, application of design principles, and enhancing critical thinking.

Methods

The goal of this study was to evaluate the effectiveness of a new corrosion engineering curriculum for enhancing student's content knowledge and complex reasoning skills. Due to the lack of corrosion engineering education in the United States, our goal was to create meaningful, real- world learning opportunities for high school students to increase their exposure to corrosion engineering. Based on the Next Generation Science Standards (NGSS, 2013) and the curriculum criteria laid out by Berland, we designed classroom modules to integrate knowledge and skills from corrosion engineering into a variety of high school courses, such as chemistry, physics, mathematics, and engineering.

Context and Data Sources

The Corrosion Engineering Curriculum (CEC) is a project-based, hands-on curriculum for high school STEM classrooms that presents real-world challenges based on vehicular corrosion. CEC is implemented as a 4-week project-based learning curriculum integrated into math or science courses (Table 1). Students must conduct laboratory and simulated experiments, carry out analysis, and develop a hands-on model based on their results. Laboratory experiments are described in Table 2. Each lesson consists of PowerPoint presentations and laboratory handouts with student worksheets. It should be noted that the CorrSim II program used in the module is a free software available at (http://corrdefense.nace.org/corrdefense_Spring2014/tech4.asp). Instructor professional development materials are also included, consisting of lesson plans, PBL Learning Experience Design (LED) template, student success rubrics, and instructional material on the laboratory and simulation activities. Each lesson is designed to contain at least one disciplinary core idea from the Next Generation Science Standards.

Table 1: Unit Plan for Corrosion Engineering Curriculum

Lesson 1: Understanding and Characterizing (1-5)	
Description	Lessons
The students are introduced to corrosion engineering from a scientific viewpoint in order to understand the parallel relationship between science and technology, and societal needs. Students are introduced to the concept that corrosion engineers are responsible of applying scientific knowledge to solve societal corrosion needs.	1. Basics of corrosion engineering 2. Infrastructure affected 3. Basics of electrochemical reactions
Lesson 2: Creating and Selecting a Concept (6-10)	
Description	Lessons
Students use design requirements and information obtained regarding customer needs to create a design. Students are introduced to corrosion design software.	4. Generating concepts 5. Selecting concepts
Lesson 3: Building, Verifying, and Refining (11-20)	
Description	Lessons
Students use computer simulation to model the impact of their corrosion mitigation solution to keep a city maintained with a budget and differing environmental conditions. Students build a model salt truck and create a set of laboratory experiments to measure and test their solutions. The goal of this lesson is for students to plan, conduct their experiments, and determine if their design meets the requirements of the project.	6. Embody the Concept 7. Test, Evaluate and Refine 8. Finalize and Share Design

The guidelines set forth from the NGSS and the Framework for K-12 Science Education were used in designing, creating, and implementing the engineering module used in this study. The overall design project was to develop a new or modified salt truck that is resistant to corrosion from deicers. Students were expected to detail and present their work, explaining how they decided on their design and why their salt truck was more corrosion resistant than other design alternatives. Evaluation of the final design was based on several criteria, such as how well the students understood corrosion science concepts, an economic cost-benefit analysis, and societal

impact on the proposed design. The presentations helped to reinforce the concepts learned in the overall corrosion engineering curriculum while encouraging student reflection.

Data Analysis

Table 2: Laboratory experiments for Unit Plan

Name	Overview	Student Activities
Corrosion at Play	The objective of this lab is to study the long-term effects of corrosion using CorrSIM II. Corrconnect software was developed by the Department of Defense (DoD) Corrosion Policy and Oversight Office to educate everyone about corrosion.	● Learning and modeling corrosion with a city simulator ● Keep a city maintained with a budget and differing environmental conditions
Environmental Factors Affecting Corrosion	The objective of this lab is to study the behavior of iron in the presence of different environments	● Examine the samples ● Compare visually the outcome of the experiment ● Rank environments from the most to least corrosive
What's it Made of?	The objective of this lab is to study the behavior of different metals in the presence of a corrosive environment.	● Examine the samples ● Compare visually the outcome of the experiment ● Rank environments from the most to least corrosive
The Cost of Corrosion	The objective of this assignment is to determine the cost of vehicular corrosion and the cost-benefit of different corrosion prevention strategies	● Calculate indirect and direct costs ● Estimate decrease in cost using Excel and CorrSim II ● Calculate cost-benefit

In order to perform assessments, pre- and post-surveys were distributed to students immediately before and after completion of the entire curriculum. Pre-surveys were used as one form of formative assessment as it provided students structure about what was expected of them upon completion of the curriculum (Capraro, 2013). Student participants (n=69) were part of a local STEM high school and the curriculum was integrated into several classes.

Table 3: Rubric for evaluation of design question from pre- and post-assessment for the question: Assume that your vehicle is experiencing corrosion during the winter months. Design a strategy that could be used to prevent corrosion. IDENTIFY what factors cause corrosion. EXPLAIN how your design provides corrosion protection. JUSTIFY your design using cost and safety. The average pre-score was 0.94 (SD = 1.07) and the average post score was 2.13 (SD = 1.03) with a p-value of 1.01×10^{-11} using a student's t-test.

Coding Category	Score	Sample Response
No response; irrelevant response	0	"I don't know"
Student is aware that corrosion is an issue yet does not correctly identify causes of corrosion or explain design	1	"Salt causes corrosion"
Student identifies causes of corrosion and provides an incomplete explanation of how to prevent corrosion	2	"If you would keep the snow and ice off the cars and the roads then the cars would not be corroded and the roads would be clear"
Student identifies causes of corrosion and provides one corrosion prevention strategies with incomplete justification.	3	"Water and salt could cause corrosion. Use warm water soluble plastic to temporarily protect the trucks important parts."
Student identifies causes of corrosion and provides at least 2 corrosion prevention strategies. Uses evidence to justify and explain design.	4	"Corrosion is caused by the vehicles contact with salt and water from the road. My design will improve corrosion because it will prevent the car from coming into contact with the ice and water. My design idea is to coat the car with acrylic coating. My design will be safe because it's just a coating and affordable because it's arcylic."

The module was implemented in various classrooms between 2014-2016. All students were informed that they would undergo a pre- and post-survey on corrosion engineering. Students were asked to respond to ten questions designed to elicit their conceptual understanding of corrosion processes, as well as their thoughts regarding corrosion related issues in society. For a summative assessment, four true/false questions were used to assess their knowledge of corrosion engineering concepts. For formative assessment, five open-ended questions focused on the impact of corrosion engineering on society and the final design question required students to describe and explain a corrosion prevention or mitigation strategy and how their design addressed the economic, safety, and societal issues they identified. We also used formative strategies like think/pair/share/, Kahoot, Venn Diagrams, Find Someone who, identifying good and bad designs from pictures, drawing and labeling electrochemical processes, calculating fast and slow reaction rates and visual comparisons of corrosive materials and environments

All responses to the design questions were initially reviewed and were scored for use in statistical analysis (Table 3). The coding analysis of the open-ended questions and design problem followed the procedure established by Riskowski et al for evaluation of a water resources engineering module (Riskowski, 2009). Mean responses for identical pre-/post-surveys were compared using a t-test to determine if there was a statistically significant different in student knowledge before and after participation in the CEC.

Findings

Prior to participation in the CEC the mean student response to the true/false questions was (M=2.9, SD=0.9), indicating that the students had some prior understanding of corrosion science. After participation, the mean student response to true/false questions increased to (M=3.22, SD=0.78). Summative assessments using the true/false questions indicated that significant differences in students' overall content knowledge, based on mean student response, increased from pre- to post- participation (t-test, p-value = 0.03). The decrease in student response mean to Question 2 indicates a possible student misconception about removal of salt in corrosion prevention and Laboratory 2 addressing the effects of soap and water on corrosion should be reevaluated. Additionally, it is difficult to remove the effect of students simply guessing correctly during the pre-assessment. The open-ended and design questions allow for a better understanding of student knowledge before and after the corrosion module.

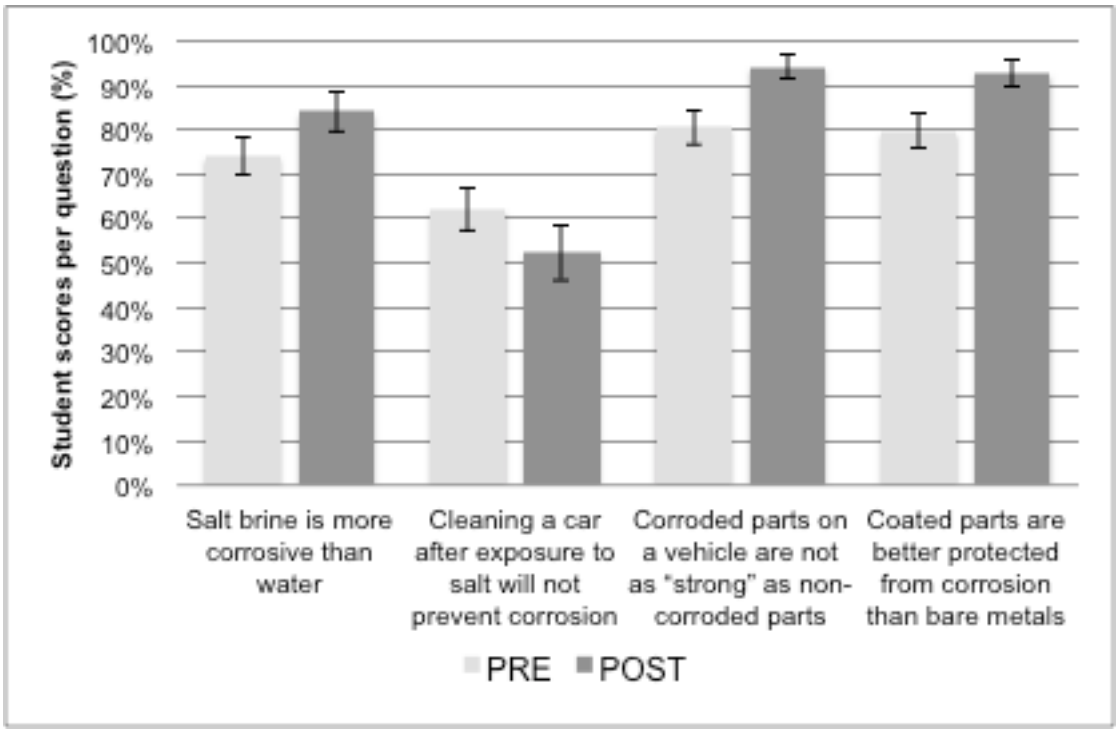

Figure 2: Comparison of student pre- and post-assessment responses to four true/false questions. A correct answer was given a score of 1 while an incorrect answer, a score of 0. The figure shows the average for each question with error bars representing standard error.

Table 4: True/false questions for pre/post-assessment. These questions were evaluated for correctness, with a correct answer receiving a score of 1 and an incorrect answer receiving a score of 0.

Question	Correct Answer	Score
Salt brine is more corrosive than water	True	1
Cleaning a car after exposure to salt will not prevent corrosion	False	1
Corroded parts on a vehicle are not as "strong" as non-corroded parts	True	1
Coated parts are better protected from corrosion than bare metals	True	1

For the open-ended questions, students were able to see corrosion as a more complex issue after completion of the CEC. Figure 3 highlights the breakdown in student response when asked, "When someone says corrosion is a problem/issue, what does that mean?" Prior to completion of the CEC, 42% of students did not have an answer or simply restated the question, while only 7% of the students recognized that corrosion was the process undergone by rusting cars and 13% mistook corrosion with erosion. After completion of the CEC, the percentage of students who did not have an answer or simply restated the question decreased to 27%, while 23% understood that corrosion was associate with rust (48% understood corrosion as a breakdown of products) and only 2% confused corrosion with erosion.

Table 5: Open-ended questions for pre/post-assessment. These questions were not evaluated for correctness, but were used to gauge understanding of corrosion related issues.

When someone says corrosion is a problem/issue, what does that mean?
What are some strategies to keep roadways clear of snow and ice?
How do these strategies affect the corrosion of vehicles and roadways?
How can we monitor the effect of snow and ice removal on the corrosion of vehicles and roadways?
What can be done to prevent corrosion of vehicles and roadways caused by snow and ice removal?

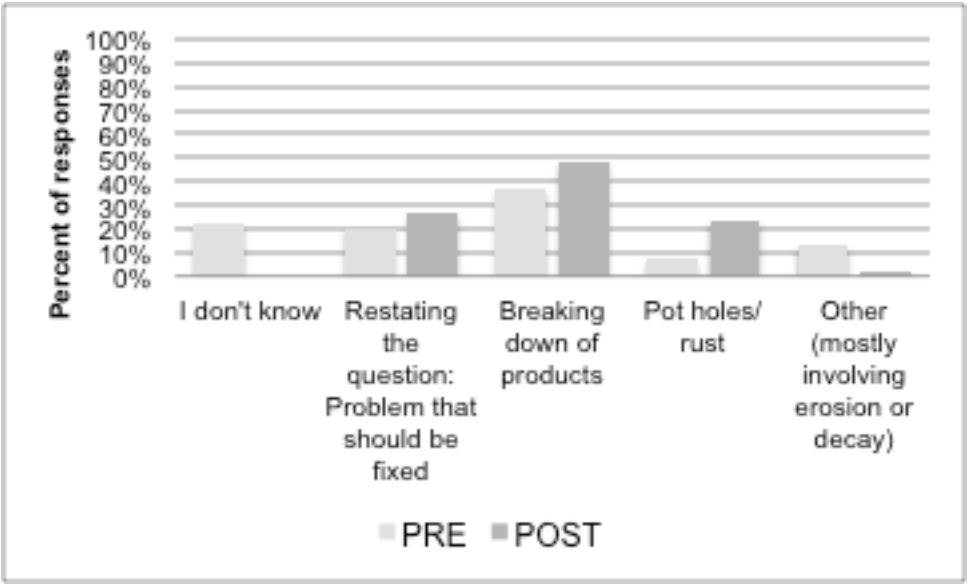

Figure 3: Breakdown of student responses to the open-ended question: "When someone says corrosion is a problem/issue, what does that mean?" Student responses were tallied before (n=108) and after (n=64) completion of the CEC. The graph indicates percentage of students with a given response.

Figure 4 highlights the breakdown in student response when asked, "What are some strategies to keep roadways clear of snow and ice?" As expected, pre- and post- surveys show that most students view salt deicers as the main strategy to clear roadways of snow and ice. However, after completion of the CEC, 5% of the students responded with alternative deicers that they explored during the PBL. When asked the follow-up question, "How do these strategies affect the corrosion of vehicles and roadways?" the effect of the CEC was more evident (Figure 5). Prior to completion of the CEC, only 50% of the students associated deicers with vehicular corrosion. After participation in the CEC, 86% of students understood the impact of liquid deicers on vehicular corrosion.

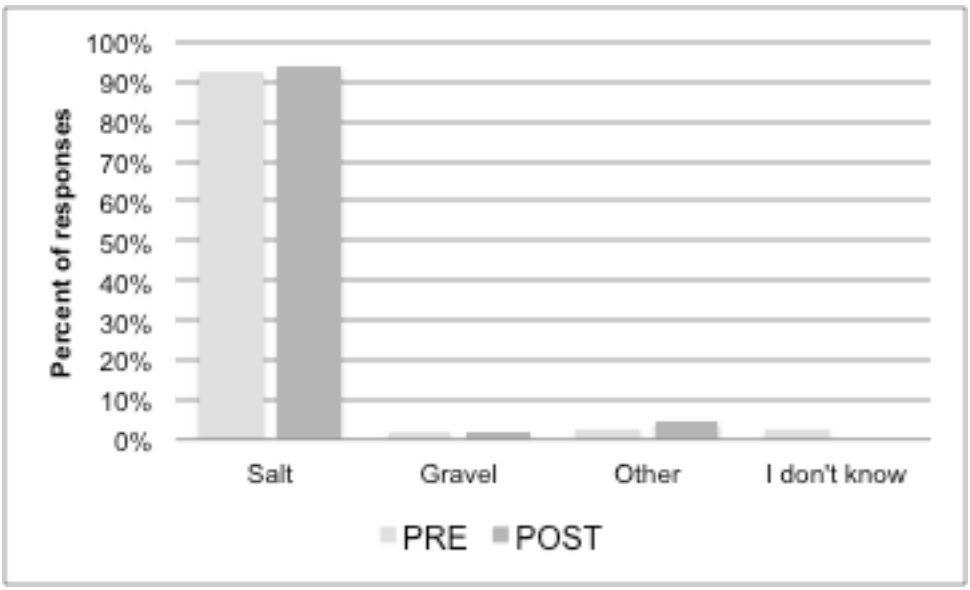

Figure 4: Breakdown of student responses to the open-ended question: "What are some strategies to keep roadways clear of snow and ice?" Student responses were tallied before (n=108) and after (n=64) completion of the CEC. The graph indicates percentage of students with a given response.

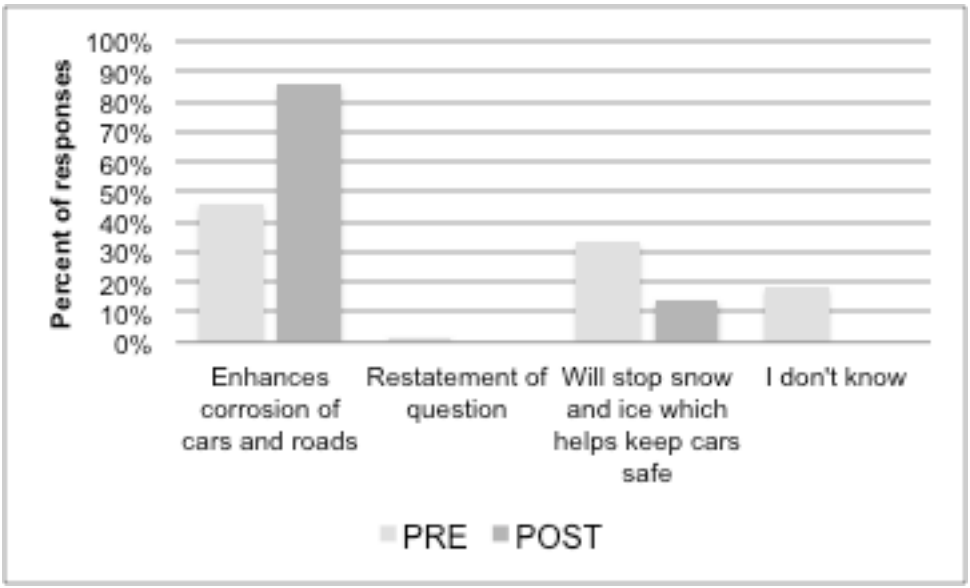

Figure 5: Breakdown of student responses to the open-ended question: "How do these strategies affect the corrosion of vehicles and roadways?" Student responses were tallied before (n=108) and after (n=64) completion of the CEC. The graph indicates percentage of students with a given response.

Students were then asked "How can we monitor the effect of snow and ice removal on the corrosion of vehicles and roadways?" Prior to completion of the CEC, 36% did not have an

answer or suggested measuring the amount of snow removed by salt (18%), while only 33% suggested visually monitoring corrosion on cars. The number of students suggesting visually monitoring corrosion on cars increased to 70% after completion of the CEC and none of the students provided an answer of "I don't know". In fact, the number of creative solutions, such as attaching a plate with different metals to a salt truck to assess their corrosion, increased (Figure 6). As a follow-up, students were asked, "What can be done to prevent corrosion of vehicles and roadways caused by snow and ice removal?" Pre-assessment results show that the majority of students did not have a response for this answer. After completion of the CEC, all students provided at least one viable corrosion mitigation strategy including washing vehicles, using coatings, changing the material make-up of vehicles, or using less corrosive deicers.

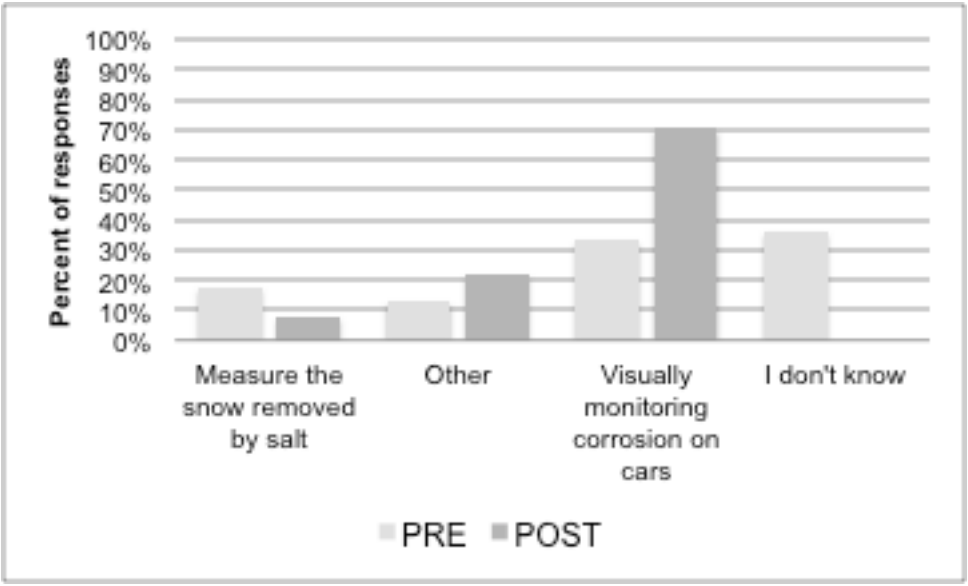

Figure 6: Breakdown of student responses to the open-ended question: "How can we monitor the effect of snow and ice removal on the corrosion of vehicles and roadways?" Student responses were tallied before (n=108) and after (n=64) completion of the CEC. The graph indicates percentage of students with a given response.

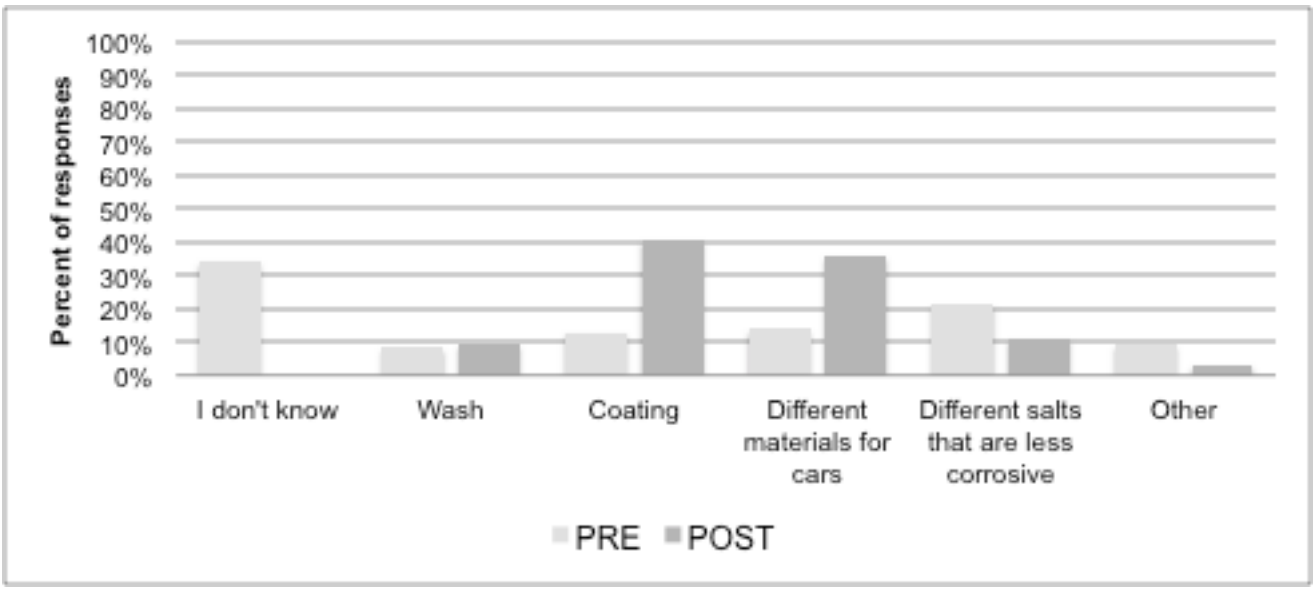

Figure 7: Breakdown of student responses to the open-ended question: "What can be done to prevent corrosion of vehicles and roadways caused by snow and ice removal?" Student responses were tallied before (n=108) and after (n=64) completion of the CEC. The graph indicates percentage of students with a given response.

Pre- and post- assessment of the design question, using the rubric in Table 3, showed a statistically significant improvement (t-test, $p = 1.26 \times 10^{-11}$) in both the complexity (number of procedural steps) and depth of understanding of corrosion mitigation solutions. This highlights the success of the CEC at increasing the student's ability to apply engineering design principles to a real-world problem. These results also indicate that students were able to not only determine the cause of the corrosion but also to come up with ways to test their hypotheses for corrosion mitigation solutions. The post-CEC assessment highlights the success of the curriculum to increase the student's higher order thinking and complex reasoning skills.

Discussion and Implications

With an increased integration of engineering into traditional science classes, more research is necessary to study their effectiveness. In this study we evaluated the influence of CEC on student's knowledge of corrosion engineering, engineering design principles, and critical thinking skills. Similar to previous work by Berland and Trauth-Nare et al, the purpose of this study was to (1) increase knowledge among high school students about the factors associated with corrosion, specifically vehicular corrosion, (2) increase student understanding of engineering principles behind corrosion prevention and mitigation, and (3) engage students in multiple interactive, hands-on activities to reinforce their learning (Berland, 2013, Trauth-Nare, 2016). The CEC curriculum is an example of a project-based curriculum as it was designed to use corrosion engineering and science concepts to solve an authentic question (vehicular corrosion). Students were presented with the corrosion problem and relevant background information as well the implications of their work on public safety. For example, in the

laboratory lessons students were exposed to different factors effecting corrosion (e.g. coatings, type of metal, and environment). The students were asked to design a salt truck (or modify an existing salt truck) using their laboratory data to quantify which design was the most corrosion resistant. A corrosion simulator was also used to determine the long-term effects of their proposed solution on city budgets and public safety. Through the design process, students learned that using coated metals, stainless steel, and washing vehicles after exposure to deicers decreased corrosion, increasing vehicle lifetime, decreasing cost, and increasing public safety.

Also similar to Berland et al and Trauth-Nare et al students were involved in design work prior to the pre-assessment, making it more difficult to determine if students already possessed the ability to apply engineering design principles or if those skills developed throughout the course of the curriculum (Berland, 2013, Trauth-Nare, 2016). Additionally, the CEC was piloted at only a single high school throughout the course of several semesters. The data were not segregated by semester due to the small sample size in each semester, thus eliminating the effect of previous background knowledge and experiences known to effect performance on learning activities (Bransford, 1999).

Similar to previous PBL curriculum (Morrison, 2015), our data revealed a significant increase in the student's corrosion engineering knowledge, application of engineering design principles, and critical thinking skills (Figures 1-6). Based on Birgili et al and Riskowski et al, assessment of student performance in the CEC was carried out using an embedded-assessment containing both summative and formative assessments (Riskowski, 2009, Birgili, 2015). True/false questions were used to perform a summative assessment on the student's content knowledge towards corrosion engineering. Open-ended and design questions were used as a formative assessment towards the student's creative and critical thinking skills in order to determine the student's ability to look at problems from different perspectives and encourage higher order thinking skills. Similar to our study, Riskowski et al, reported an increase in content knowledge and an increased understanding in critical thinking skills and engineering design principles after students participated in an engineering design module on water resources management (Riskowski, 2009). Future assessment must be done to determine the effect of the CEC on the long-term understanding of corrosion engineering.

Through the development of the CEC, it is our hope that the CEC unit plan will be adopted in a wide range of classrooms containing students from diverse backgrounds in order to further evaluate the effectiveness of the curriculum for promoting knowledge of corrosion science and engineering and increasing critical thinking and engineering design skills. During the initial phase of curriculum development, the CEC developers taught the lessons and therefore had ample experience with the topics covered in each CEC lesson. Once the lessons are more widely distributed, however, it will be crucial to track if the same student outcomes are generated. As such, the CEC lessons and laboratory materials contain detailed information and development materials to aide instructors in future implementations. Additionally, teachers must be prepared to guide students in PBL assessment. According to a study by Capraro and Corlu, teachers must have the pedagogical skills necessary for supporting student learning and assessment in a project-based curriculum if the curriculum is to be successful (Capraro, 2013).

Conclusions and Future Work

In this work, we presented a preliminary analysis on the effectiveness of the project-based CEC for promoting students' corrosion engineering knowledge, engineering design skills, and increasing critical thinking. Our data indicated the efficacy of the CEC curriculum on students' core corrosion engineering knowledge as well as their higher order thinking skills. Clearly, early intervention of students to enter engineering fields is imperative in producing a skilled workforce in the United States. Corrosion engineering is particularly at risk, due to the lack of structured corrosion engineering courses in elementary and secondary schools (NRC, 2009).

Evidence clearly shows that engaging elementary and secondary students in engineering design yields positive learning outcomes. One of the most intriguing potential benefits of K12 PBL curriculum focused on engineering education is the enhanced interest in engineering due to the relevance of these curriculum to real world problems. Previous studies have shown the success of similar modules at increasing student interest in engineering (Trauth-Nare, 2016). Initial survey results of a small sample set show that 81% of the students felt that they learned something from the CEC with 68% stating that they would recommend the CEC to a friend and 50% indicating they had a positive experience. These results were collected on only the most recent participants and therefore future research should focus on assessing the effect of the CEC at increasing interest in corrosion engineering, or engineering in general. Once the curriculum has been implemented in more classrooms, detailed information can be obtained regarding student interest and likelihood of students to further study corrosion engineering at the college level. It is our hope that widespread implementation of the CEC will help fix the "rusty" pipeline associate with corrosion education.

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