Maximizing Student Creativity in Complex Wastewater Engineering Design

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ABSTRACT

While wastewater treatment in the United States is currently aimed at achieving pollutant discharge limits, advances in biochemical treatment are shifting the industry's focus to energy and nutrient recovery. Recovering nutrients from wastewater may very well be required for future wastewater treatment plants. Indeed, the term "wastewater treatment plant" is already changing to "water resource recovery facility." An emphasis on fundamentals to enhance the educational focus on current biochemical treatment methods could best prepare our students for success in a future requiring different techniques than those commonly used at this time. A strong ability to analyze and apply reduction-oxidation reactions will be essential for environmental engineers who will design future systems. Teaching common reduction-oxidation equations using a number line may help students visualize and quantify energy requirements associated with carrying out these chemical reactions, and it can prepare students for a future requiring new treatment aims and strategies. Our students anecdotally struggled with reduction-oxidation reactions, so we investigated how to address their concerns. We determined they were likely to be primarily visual learners, and we confirmed through the use of a survey that this was the case. We identified visual teaching tools we were using, we developed the number line as a new teaching tool, and we implemented the number line in two applicable courses. Here, we assessed classroom implementation of a number line in teaching environmental reduction-oxidation reactions compared to other teaching methods. Preferences for different teaching tools indicate the number line was preferred at least as much as other teaching tools among environmental engineering students.

Keywords: environmental engineering education, sustainability, redox reactions, learning styles

Background and Introduction

The need for sustainability and advancements in our knowledge of microbial systems has led to and will continue to lead to advancements in wastewater treatment. Developments include techniques to help recover water and key nutrients from wastewater [1]. However, wastewater treatment in the United States currently requires only compliance with emissions standards [2]; this generally results in significant releases of carbon and nitrogen into the atmosphere at the expense of significant energy consumption [3]. Future conservation requirements and advances in treatment methods may very well drive legislation, and continue to drive markets and industry, toward energy and resource recovery.

Adapting the wastewater treatment industry from carbon and nitrogen removal to recovery requires revolutionary processes. Developing and implementing revolutionary processes in an uncertain future in any industry requires significant emphasis on fundamentals [4,5]. A stronger emphasis on fundamentals can compliment our focus on current design, and it will encourage advancements leading to the design of even more effective treatment techniques. Our students will hopefully be more innovative and entrepreneurial within wastewater engineering with an increased focus on redox fundamentals. Students now will be engineers and business leaders in the future, and they will provide more value to society with an increased understanding of the fundamentals.

Mastering fundamentals in wastewater treatment requires a solid grasp of reduction-oxidation (redox) chemistry. Carbon and nitrogen are readily manipulated by biochemical processes involving redox reactions. A simple number line has been used to teach redox reactions to students in the past [6], so this method could be easily implemented for environmental redox reactions. The oxidation states of elements within many compounds can be easily determined through safe assumptions that hydrogen is generally at +1 and oxygen is generally at -2 [7]. The common element of interest within each compound can be plotted on a number line as in Figure 1. Reduced compounds are to the left, and oxidized compounds are to the right. Redox reactions can be depicted on the number line as well with arrows as elements either gain or lose electrons.

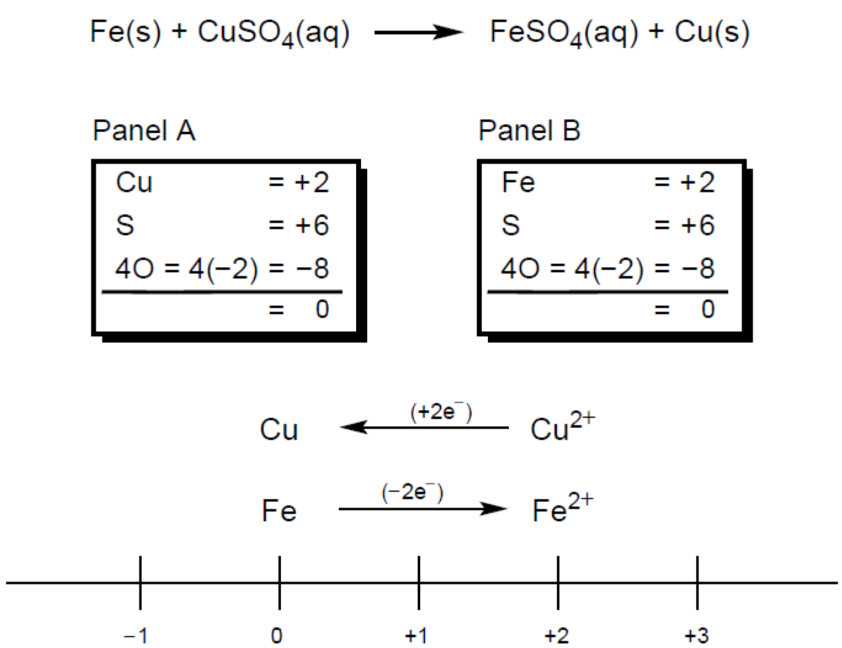

Figure 1. An example of a number line's use in depicting redox reactions [6]. Oxidation states of various compounds can be determined through various methods, the oxidation states of elements of interest within each compound can be plotted, reduction can be depicted by an arrow moving to the left, and oxidation can be depicted by an arrow moving to the right.

Previous research shows that engineering students prefer visual techniques over other learning styles [8-10], so perhaps developing more visual tools will make redox fundamentals more accessible to more students. More work is required, however, for discipline-specific learning style preferences within engineering. Environmental engineers may generally have more or less of a preference for visual learning than civil engineers, for example. Either way, our students were expected to be strong visual learners based on previous research indicating that engineering students prefer visual learning, but the extent to which our students prefer visual learning cannot be accurately predicted.

Previous work from this group focused on the development of teaching tools for environmental redox reactions [11]. Detailed number lines for carbon and nitrogen were developed and were used as teaching tools in two applicable, undergraduate courses in order to address student concerns with redox chemistry. This study assesses implementation of number lines as teaching tools in environmental engineering classrooms. Students anecdotally preferred the number line over other teaching methods, so results were expected to show that student preference for the number line was at least similar to preferences for other tools.

Methods

Learning Styles

Learning styles were assessed using an externally-developed survey [12]. Respondents answered 14 questions about how they typically handle different situations. Each question had three possible responses to choose from, where one corresponded to a visual response, one corresponded to an auditory response, and one corresponded to a kinesthetic response. The number of visual, auditory, and kinesthetic responses were totaled for each respondent. Each respondent, then, had composite scores for visual, auditory, and kinesthetic learning preferences which totaled 14.

Teaching Tools

Classroom implementation of number lines occurred in two undergraduate courses over the course of one semester. Number lines for redox reactions involving carbon, hydrogen, oxygen, nitrogen, sulfur, and chlorine were developed and built upon throughout the semester. The courses assessed included significant analysis of redox reactions in aerobic respiration, photosynthesis, fuel cells, nitrification, denitrification, anammox, dissimilatory nitrate reduction to ammonium, anaerobic digestion, fermentation, sulfide production, and various forms of disinfection. Simplified examples of internally-developed number lines for common environmental redox reactions involving carbon and nitrogen were published previously [11].

The first course assessed in this study was Environmental Biological Systems (EV396). EV396 is largely an environmental microbiology course; however, it is a hybrid of both science and its applications within engineering. EV396 is required for environmental engineering majors, and it is a popular elective among environmental science majors. Enrollment from the assessed semester was 18: nine environmental engineering majors (all juniors), eight environmental science majors (juniors and seniors), and one engineering psychology major (junior). EV396 is a prerequisite for the second assessed course: Biochemical Treatment (EV402). EV402 focuses primarily on applying biochemistry in wastewater engineering, and this course is required for environmental engineering majors. Enrollment from the assessed semester was 10 environmental engineering majors (all seniors). Four instructors especially familiar with environmental redox reactions were also surveyed.

Student and instructor preferences for the number line and other teaching tools were quantified on a Likert-type scale using an internally-developed survey focused on the nitrogen cycle, as opposed to the carbon cycle, for consistency and for relative simplicity. Preferences are compared, and respondents' learning style preferences are also compared to their teaching tool preferences. Respondents were shown different representations of the nitrogen cycle: a number line (Figure 2), a picture (Figure 3), and a circle (Figure 4), and they were asked to choose if each was "an effective tool / method for learning and analyzing nitrogen cycle redox reactions in environmental engineering." Students also assessed "Hands-on learning (like using nitrogen test kits in a lab / in class demos)." Nitrogen test kit use was also considered partially visual because of the change in color that occurs during the tests. A score of 1 represented "strongly disagree," a score of 2 represented "disagree," a score of 3 represented "neutral," a score of 4 represented "agree," and a score of 5 represented "strongly agree."

Students were exposed to each of the teaching tools assessed in the survey throughout the course of the semester. Teaching tools were built – not simply presented – to reinforce material learned in previous courses. Surveys were administered near the end of the semester (during lesson 36 of 40 or later) so they had adequate exposure to each tool. Surveys were completed anonymously, but students were asked to indicate their majors.

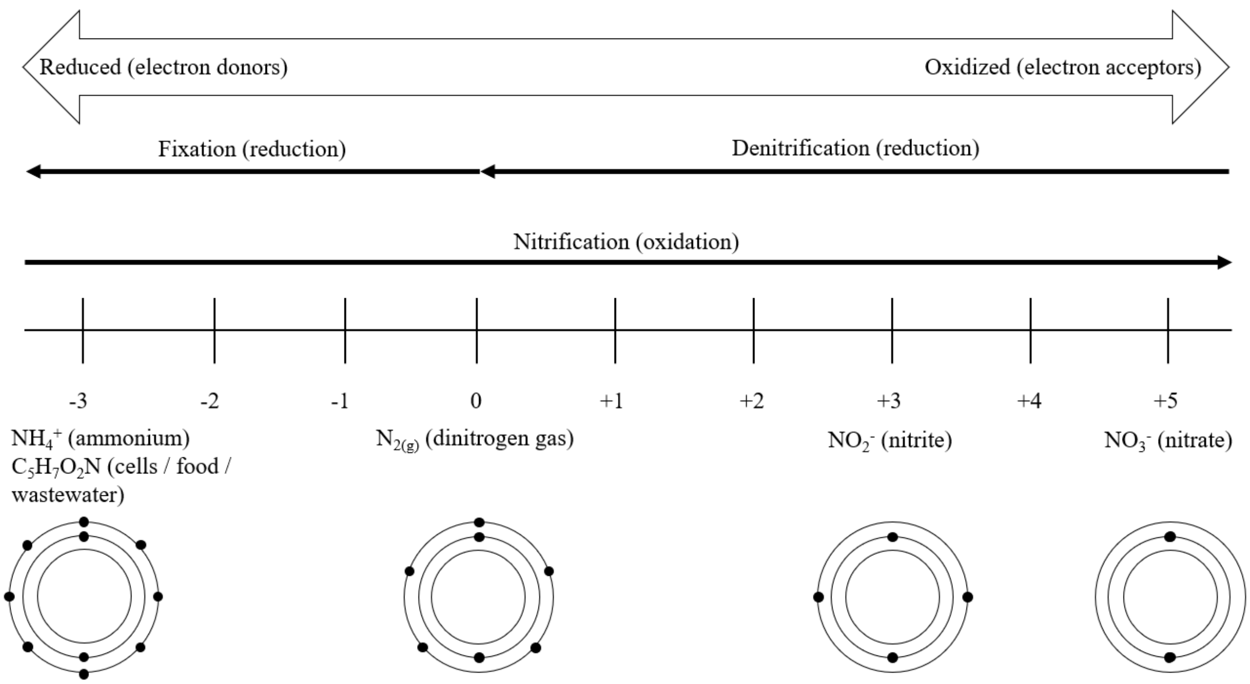

Figure 2. This number line depicts oxidation states of key nitrogen species. Movement along the line from one species to another is accomplished through redox reactions and represented by the thinner arrows. The change in nitrogen's oxidation state represents the number of electrons lost or gained per nitrogen atom in the reaction. This is adapted from previous work this group published [11].

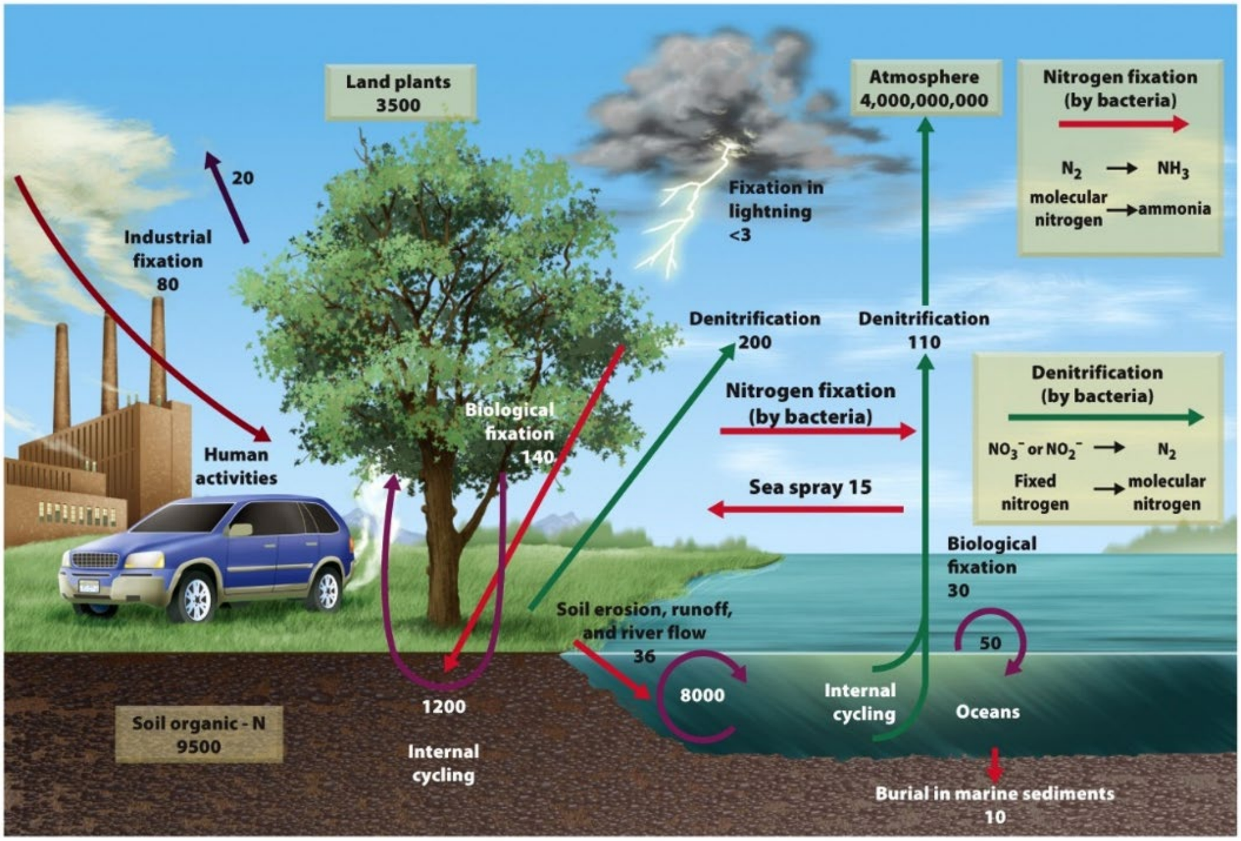

Figure 3. This picture depicts the nitrogen cycle; numbers represent millions of metric tons of nitrogen transferred or stored annually [13].

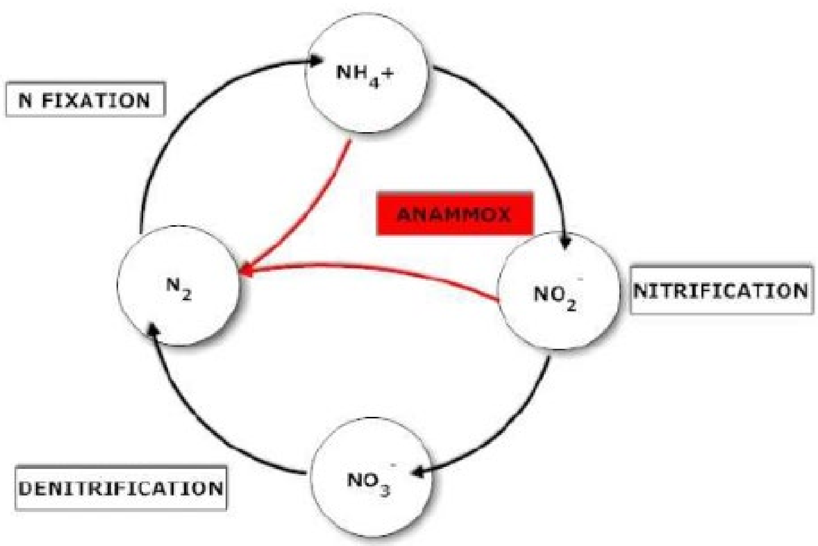

Figure 4. This circle depicts the nitrogen cycle. Arrows represent key redox reactions which occur as nitrogen is transformed from one species to another [14].

Results and Discussion

Learning Styles
Results from the learning styles survey support our initial assumption that our students were primarily visual learners. This suggests that developing visual tools to enhance learning may be an effective method for maximizing learning. Composite scores for each learning style represented number of responses to questions corresponding to each respective learning style. There were 14 questions, so composite scores are on a 14-point scale where 1 represents one response preference to a question, and 14 represents all 14 responses for a specific learning style.

Environmental engineering students preferred visual learning (M=6.97, 95% CI [5.95, 8.00]), followed by kinesthetic (M=3.84, 95% CI [2.73, 4.96]) and auditory (M=3.39, 95% CI [2.45, 4.34]). Non-environmental engineering students preferred visual learning (M=7.89, 95% CI [7.00, 8.78]), followed by auditory (M=3.22, 95% CI [2.15, 4.29]) and kinesthetic (M=2.89, 95% CI [1.38, 4.40]). Overall, students preferred visual learning (M=7.27, 95% CI [6.51, 8.03]), followed by kinesthetic (M=3.54, 95% CI [2.64, 4.43]) and auditory (M=3.34, 95% CI [2.62, 4.06]). See Table 1 for a tabular depiction of learning style results.

Table 1. Learning style preferences for each demographic surveyed are presented here. Students indicated a strong preference for visual learning.

		Learning Style					
Population	**n**	**Visual**	**95% CI**	**Auditory**	**95% CI**	**Kinesthetic**	**95% CI**
All Students	28	7.27	[6.51, 8.03]	3.34	[2.62, 4.06]	3.54	[2.64, 4.43]
EV ENG Students	19	6.97	[5.95, 8.00]	3.39	[2.45, 4.34]	3.84	[2.73, 4.96]
Non EV ENG Students	9	7.89	[7.00, 8.78]	3.22	[2.15, 4.29]	2.89	[1.38, 4.40]

*Scores represent number of survey questions for which the respective learning style was the preference. The survey contained 14 questions, so the minimum score possible was 0, and the maximum score possible was 14.

Teaching Tools
Survey results suggest that the number line is preferred at least as much as other teaching tools for analyzing redox reactions. Scores are on a 5-point Likert-type scale, where 1 corresponds to students strongly disagreeing that the tool is effective, and 5 corresponds to students strongly agreeing that the tool is effective.

Environmental engineering students had a stronger preference for the number line than did non-engineering students. Environmental engineering students preferred the number line (M=4.16, 95% CI [3.93, 4.38]), followed by hands on learning (M=3.79, 95% CI [3.38, 4.20]), the circle (M=3.42, 95% CI [2.92, 3.93]), and the picture (M=3.16, 95% CI [2.65, 3.66]). Non-engineering students preferred the picture (M=4.22, 95% CI [3.79, 4.66]), followed by the number line (M=3.67, 95% CI [3.01, 4.32]) and hands on (M=3.67, 95% CI [3.20, 4.13]), and the circle

(M=3.44, 95% CI [2.87, 4.02]). Overall, students preferred the number line (M=4.00, 95% CI [3.73, 4.27]), followed by hands on learning (M=3.75, 95% CI [3.44, 4.06]), the picture (M=3.50, 95% CI [3.09, 3.91]), and the circle (M=3.43, 95% CI [3.05, 3.81]). See Table 2 for a tabular depiction of teaching tool preferences.

Table 2. Results for teaching tool preferences are presented here. Overall, students preferred the number line at least as much as they preferred other tools.

		Teaching Tool							
Population	**n**	**Number Line**	**95% CI**	**Picture**	**95% CI**	**Circle**	**95% CI**	**Hands On**	**95% CI**
All Students	28	4.00	[3.73, 4.27]	3.50	[3.09, 3.91]	3.43	[3.05, 3.81]	3.75	[3.44, 4.06]
EV ENG Students	19	4.16	[3.93, 4.38]	3.16	[2.65, 3.66]	3.42	[2.92, 3.93]	3.79	[3.38, 4.20]
Non EV ENG Students	9	3.67	[3.01, 4.32]	4.22	[3.79, 4.66]	3.44	[2.87, 4.02]	3.67	[3.20, 4.13]

*Scores correspond to a Likert-type scale, where 1 indicates that students strongly disagree that the tool is effective, and 5 indicates that students strongly agree that the tool is effective.

While all tools should not be discounted, universities not already using the number line to teach redox reactions may benefit from employing it by increasing environmental engineering students' comfort levels in classrooms. Perhaps the depictions of electron orbitals under the number line help emphasize that electrons gained leads to a more negative charge, not a more positive charge. This gain corresponding to a negative number has been shown to confuse students previously [6].

Four instructors familiar with environmental redox reactions were also surveyed, including the two instructors who taught the two courses assessed in this study. Instructor preferences were for the number line (M=4.75, 95% CI [4.26, 5.24]), the circle and hands on (each M=3.25, 95% CI [2.31, 4.19]), and then the picture (M=2.75, 95% CI [1.81, 3.69]). While the possibility of instructor bias toward the number line should be acknowledged, higher student than instructor preference for the picture suggests that instructors' personal biases did significantly not influence student teaching tool preferences.

Conclusions

Our environmental engineering students have historically struggled with grasping redox reactions. We confirmed that they were primarily composed of visual learners, and we developed an additional teaching tool for visual learners to supplement previous teaching tools. Students' preferences for different teaching tools were assessed using the nitrogen cycle. A number line developed within this research group, a picture, a circle, and hands on learning techniques were used throughout two environmental engineering courses. Student preferences indicated that the number line was preferred at least as much as the other three teaching tools. Increased student comfort with material through the use of additional techniques may lead to increased inclusivity in the classroom and make the material more accessible to more students.

Perhaps other populations dominated by visual learners would also benefit from the use of a number line when learning about redox reactions.

The abilities to think deeply about environmental problems and develop low-cost, environmentally-friendly solutions require strong emphasis on fundamentals. Our students need to be able to analyze environmental chemical reactions very effectively to develop novel remediation techniques. This work suggests that the use of a number line may be at least as effective as other common teaching techniques in enabling a deeper understanding of course material involving redox reactions.

Future work will focus on assessing each tool's effectiveness. Students will each be asked to select a tool in solving a problem, and their answers will be correlated with the chosen tool. This will identify how well each tool works when solving redox reaction-related problems. Longitudinal studies within our institution, ideally coupled with similar studies at other institutions, would lead to increased statistical significance when quantifying preferences for teaching tools and learning styles and ultimately set our students up for success when developing solutions for environmental problems in the future.

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Luke Plante is a Major in the United States Army and an Assistant Professor in the Department of Geography and Environmental Engineering at the United States Military Academy. He is a 2008 graduate of the United States Military Academy with a B.S. in Environmental Engineering and graduated from Columbia University with an M.S. in Environmental Engineering in 2016. He teaches Environmental Biological Systems, Environmental Science, Environmental Engineering Technologies, Introduction to Environmental Engineering, Advanced Individual Study I-II, Biochemical Treatment, and Officership.

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