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Hands-on Activities to Improve Students' Conceptual Understanding of Water Hardness

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Abstract

Hardness removal is a topic typically covered in water treatment courses. Students commonly hold misconceptions about what is meant by hard water. This paper explores hands-on activities centered around hard water to improve students' conceptual understanding of what hardness is and its associated problems. As a pre-assessment, students were asked to define hardness in the context of water quality then describe what problems it causes. They were then guided through two short in-class activities designed to illustrate the impacts of hardness. Students washed dirty glass beakers using soft or hard water using equal amounts of liquid soap. They observed the difference in the quantity of suds generated as well as the buildup on the beaker following rinsing and air drying. Later, in a separate activity, they measured hardness using titration kits using different water samples: bottled water, distilled water, tap water, and water softened using a home water softener. Using the hardness scale, they classified the water samples as being soft, moderately hard, hard, or extremely hard. These activities preceded lectures covering the formal definition of hardness, calculation of total hardness, the lime/soda ash water softening process, and ion exchange. Students enjoyed these activities with some showing increased interest by bringing in additional water samples from home or other locations on campus. Pre-assessment results revealed that a majority of the students were confused about the source of hardness with 0% reporting a completely correct definition, 42.8% a partially correct definition, and 57.2% reporting a completely incorrect definition. However, 64.3% knew that it causes buildup on surfaces. Post-assessment conducted via exams revealed that students' conceptual knowledge improved and from midterm to final exam.

Introduction and background

Active learning techniques are widely purported to improve student learning by appealing to a larger range of learning styles. In particular, hands-on activities have been shown to appeal to students with sensory, visual, and active learning styles [1]. Deeper learning also takes place when students can connect ideas that are familiar to them with new ones [2]. Within the context of environmental engineering, many authors have demonstrated the effectiveness of incorporating hands-on water treatment activities in the classroom including using household water filters [3], backpacking water purification systems [4], drinking water taste-tests [5] student-built water filters [6], and constructed wetlands [7].

One topic within environmental engineering with fewer reported hands-on activities is that of hard water. Water hardness is caused by the presence of multivalent cations, the most common of which are Ca^{2+} and Mg^{2+}. Students often hold misconceptions of what hardness is and what problems it causes. During informal conversations taking place during a previous offering of the course, students said that they thought hard water was associated with ill health effects and caused pipes to corrode. Nearly all were unclear about what causes hard water. Given this experience, a new approach was sought to help students better understand what water hardness is, why it is a problem, and why it is important to remove in certain situations.

A review of ASEE Conference proceedings revealed that other courses in Water Treatment courses have labs associated with their classes where a titration lab following procedures such as those outlined in the *Standard Methods for the Examination of Water and Wastewater* is conducted to measure hardness in water samples [8]. Only two papers present alternative approaches to teaching water hardness and removal concepts [6], [9]. These two papers are described below.

Researchers at the University of Toledo implemented active and collaborative learning techniques in their undergraduate and graduate-level water treatment courses to improve students learning of the precipitative softening. Their technique involved having student groups generate their own questions around the subject of hardness and compared their results to a control group that learned through a traditional passive lecture. They used keyword analyses to measure the active and control group's ability to answer questions regarding water hardness and precipitative softening. Their results indicated that this particular technique yielded mixed results. On some questions, students from the active group performed better than those in the control (passive learning) group. Among the graduate student participating in the active approach, the questions they generated were nuanced and thoughtful and required the instructors to cover unplanned topics in class [9].

Others describe using a hybrid Problem-based Learning (PBL) and traditional laboratory structure to help connect course material to real-life situations. As part of the course, students were tasked with developing a water treatment system that would treat Ohio River water such that it would be compliant with EPA regulations. Students conducted traditional water treatment labs including measuring water hardness to assess the water quality, and at the end of the semester competed with one another to build the effective treatment system. The authors reported that this technique improved students' attitude toward the course. However, they did specifically address student learning [6].

The activities and assessment described in this paper were implemented in a three-credit Water and Wastewater Engineering course at Elizabethtown College. The course is a required elective for students majoring in engineering and concentrating in environmental engineering. Students in other concentrations may also take the class as an elective. This course has a prerequisite of General Chemistry, and roughly half the students had previously taken Introduction to Environmental Engineering. Within this particular curriculum, no such lab is available. Therefore, hands-on in-class minilabs and activities are provided to enhance the regular classroom structure. The class consisted of fourteen students all juniors and seniors. The large majority of most classes (50-60 minutes out of 80 minutes) is devoted to the quantitative and analytical aspects of the course. Less time is spent on the conceptual material. Specifically, within the water treatment unit, students learn how to calculate hardness given a water quality data. They also learn how to calculate the amount of lime and soda ash that would be required to soften water.

Methods

Classroom activities

The two classroom activities were performed by groups of two to three students. Each took approximately 30 minutes of class time. The activities were conducted at the end of class. They required about one hour of preparation from the instructor and 5-10 minutes of clean up afterward with the assistance of the students.

The first class activity had students wash glassware using distilled water or tap water. Students observed the difference in the quantity of suds produced using the same amounts of water and lab soap. After the dishes had been washed, they were rinsed with the same water used with the soap and then air dried on a drying rack in the classroom. Students observed the difference in the beakers in the next class session.

For the second activity water sample were collected and tested for hardness. Tap water, bottled water, water that had been softened through a domestic water softener, and distilled water were used. Additionally, one commuter student brought in water from her house that she knew to be extremely hard.

Hardness measurements were conducted using Total Hardness Test Kits (Hach, Loveland, CO). The kit uses a titration method. Students used a dropper to add the titrant to 10 milliliters of sample water. Based on the number of drops, the students can determine the mg/L of $CaCO_3$ in the sample. Students used the hardness scale found in their textbook to categorize each water sample.

Lecture and Associated Assignments

The instructor briefly discussed hardness in three different class sessions. The first lecture is on common constituents (physical, chemical, and biological) in source water. Hardness is mentioned as a chemical characteristic of water. The second lecture focused on coagulation, flocculation and the lime-soda ash process. In this lecture, a formal definition of hardness is provided, and carbonate and noncarbonate hardness are introduced. Three class sessions later, the ion exchange process is described. As a part of that lecture, domestic water softening is discussed.

Students completed two homework problems that involved calculating total, noncarbonated, and carbonate hardness. One of those problems also involved calculating the lime and soda ash necessary for removing hardness in a particular water sample. Both of these problems came from the course's textbook, *Unit Operations and Processes in Environmental Engineering* [10].

Assessment

Before lecturing on the topic of water hardness or completing activities described above, students completed a pre-assessment in class asking them to define what is water hardness is and list problems associated with hard water. This pre-assessment was ungraded. Specifically, the following questions were asked.

1. What is water hardness?
2. What problems does hard water cause?

The answers to these questions were not specifically addressed in follow-up classes. However, the technical definition of hard water and a short discussion of engineering problems involving hard water was briefly discussed in a later lecture on water softening using the lime soda ash process.

The first graded assessment of students' conceptual understanding of hardness took place during the midterm exam in mid-October was evaluated with three short-answer questions:

1. Provide a technical definition of hard water.
2. List two problems that hard water causes.
3. List two methods for softening hard water.

In addition, they completed one computational question that required them to take water quality data and calculate the dosage of lime and soda ash required to soften the water (Appendix A). Students were presented with information that was irrelevant to softening, so they had to use the definition of hard water in order to correctly determine the total hardness, carbonate hardness, and non-carbonate hardness. Then they could proceed to determine the proper lime and soda ash dosages.

The last assessment took place on the final exam where students were required to provide a technical definition of hardness, list two problems associated with hard water, and describe two water treatment methods that can be used to remove hardness. These questions were presented in the same way as the conceptual questions from the midterm exam.

Results

Defining water hardness

In the pre-assessment exercise, students were asked to define hardness or describe the cause of hardness. Many students knew that calcium was involved, but no students could provide an exact definition. Some examples of students answers include:

"$CaCO_3$ amount in the water."

"Water hardness is the amount of calcium in the water."

"Water hardness is the presence of Ca in the water."

Other students were even less familiar providing such answers as:

"Water hardness is when the water has many small particles in it, even after treatment."

"high mineral content"

"Not sure what it is. My educated guess is that it clogs pipes."

Students were more acquainted with the problems associated with hardness with many of the citing issues such as residue and buildup in pipes. A couple of students knew that it reduced the effectiveness of soaps causing decreased lathering.

On the midterm exam, the students were asked to provide a technical definition of hard water. 64.3% were able to provide a correct answer, 14.3% a partially complete answer and 21.4% an incorrect answer (Figure 1). Two correct answers were accepted. By the final exam students further improved with 71.4% providing a correct answer, 14.3% a partially correct answer and 14.3% earning no credit.

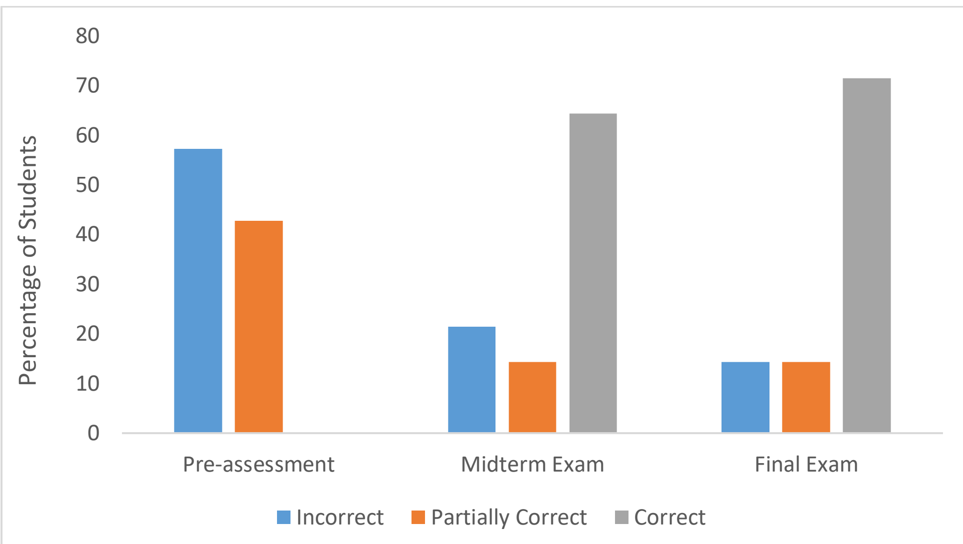

Figure 1. Results from Pre-assessment, midterm exam, and final exam when students were asked to define what water hardness

The results from the conceptual question were compared against students answers from a computational problem where students were given water quality data that they had to use to calculate the necessary lime and soda ash doses required to soften the water. This type of problem requires students to calculate the total hardness of the water sample. The water quality data included the following divalent cations: Ca^{2+}, Mg^{2+}, and Fe^{2+}. Many students neglected to include the Fe^{2+} concentration in their calculation of total hardness forgetting that other divalent cations such as Fe^{2+} contributed towards hardness. However, all but one student correctly included Ca^{2+} and Mg^{2+} in their determination of the hardness in water.

There was a high correlation between students answering the computational question and those answering the conceptual question correctly. Six out of fourteen students found the total hardness correctly including all the appropriate cations. Those same six students also provided a correct definition of hardness. Another six students knew the process of calculating total hardness but forgot to include the Fe^{2+} in their analysis. Interestingly, these same students provided definitions to the conceptual question that were to the effect of "water containing 100 mg/L or more $CaCO_3$" or water containing a high concentration of "magnesium and calcium." The two students who incorrectly tabulated hardness were also the ones that provided an incorrect definition of hardness.

Problems associated with hardness

In the pre-assessment students were more familiar with some of the problems associated with hardness (Figure 2). A majority of the students mentioned "build up" or "residue." Students were less likely to know that water hardness results in decreased lathering of soaps and detergents.

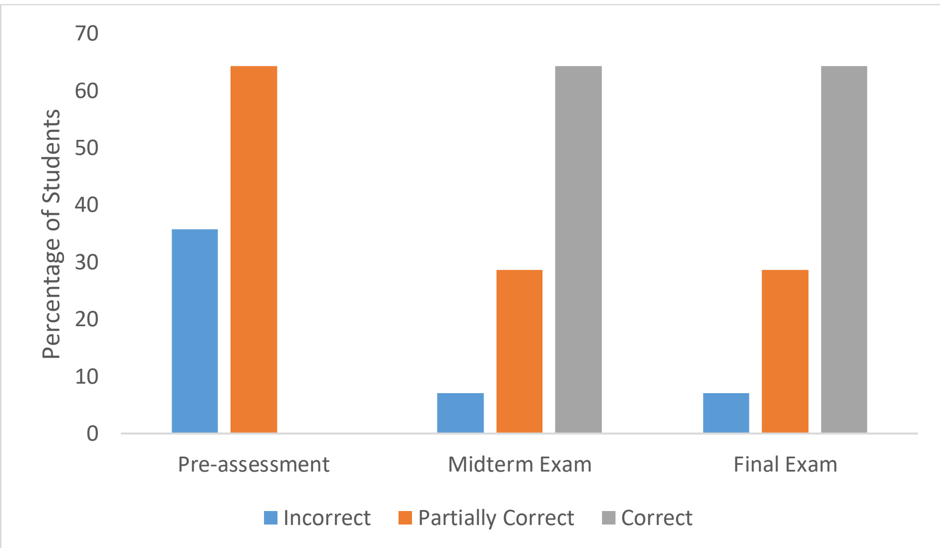

Figure 2. Results from pre-assessment, midterm exam, and final exam when students were asked with listing two problems associated with water hardness

On the midterm and final exams students were asked to list two methods of removing hardness from water. This question required them to remember the unit processes discussed in class and what constituents they remove. Nearly all of the students recalled the lime and soda ash process (Figure 3). However, numerous students only provided one method instead of two. By the final exam, however, the majority of the class remembered other methods, particularly, ion exchange. One possible reason for this is that students presented projects as a method of reviewing for the final exam.

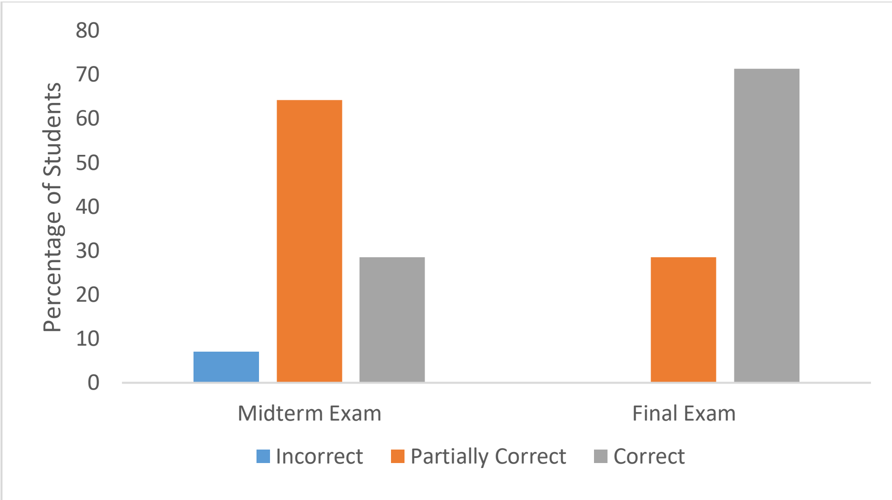

Figure 3. Results from midterm and final exams when students were asked to describe two methods of removing water hardness

Post-exam student feedback

In a follow-up survey, conducted after the semester ended. Students provided reflections on whether or not the activity helped them better understand the concept of water hardness. They also were asked to provide their input on how to improve the activity in the future. Representative quotes are provided below:

"I really like hands on experiments in class because they help me better understand the material taught in class and apply it to real world scenarios. During the water experiment, I realized that [College Name] has pretty hard water. I was then able to tie together how hard water impacts its environment. For example, I can see the build up (sic) of minerals on the faucets and my water bottle that occur from hard water. I also notice that I use more soap when I'm at school then when I am at home with my water softener."

"Prior to doing that activity, I didn't understand the concept of "water hardness." I didn't know that it could cause problems in the pipes and faucet outlets. After doing the activity, I realized it can cause a build up of Ca and Mg and cause problems to the homeowner, company, etc. I thought it was a positive use of our time in class. It was also fun because we made the activity, almost like, a competitive game (to see who had the hardest water)."

"I thought that the activity was a useful tool to learn about water hardness, but I think the experiment would benefit from a more varied water type representation. For example, if different groups had different unknown water samples which they tested and then came back together to see which group received which sample that would be interesting."

Conclusions

Incorporating the hands-on activities involving water hardness appeared to improve students' conceptual understanding of what hardness is and why it is a problem. The results also showed a connection between students' conceptual understanding of what hardness is and their ability to correctly tabulate total hardness as part of the process of determining lime and soda ash dosages. The majority of the students appeared to retain the knowledge from the midterm exam in October until the final exam in December. This result is interesting because the instructor did not specifically review these concepts with the students following the midterm exam. One possible reason for the consistent performance on the final is that student groups wrote short stories on the journey of water through the water and wastewater treatment process. These short stories were performed in class a method of reviewing for the final exam. During these recitations, student teams revisited the concept of hard water and described precipitative water softening process.

Unfortunately, an appropriate control study could not be established because this was the second offering of the course at this institution and by this instructor. The first time the course was offered was two years before with only seven students. Therefore, a meaningful comparison was not available. Future research, possibly at larger institutions with multiple sections should examine this technique along with a control to assess the effectiveness of this approach further. Also, this class did not have a requisite laboratory so it would be meaningful to compare these results to other courses with laboratories that conduct water hardness tests in that setting.

The activities described in this paper were inexpensive and required a relatively low time commitment. All the materials were easy to procure. The students greatly enjoyed the activities as evidenced by students requesting to bring in additional water samples to class to test the water hardness and a post-semester student survey. The instructor plans to continue to refine these activities and assessments in future offerings of this course.

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Appendix A – Sample Midterm Exam Question

1. A municipal water treatment plant is tasked with softening its water using the lime/soda ash process. The facility treats 3 MGD (million gallons per day). Given the water quality analysis below, determine the following: (10 points)

   a) Total amount of lime required on a weekly basis (lb/week).
   b) Total amount of soda ash on a weekly basis (lb/week).

Constituent	mg/L	meq/L	mg/L as $CaCO_3$
Ca^{2+}	110	5.49	274
Mg^{2+}	50	4.11	206
CO_3^{2-}	70	2.33	117
Fe^{2+}	3	0.11	5
Cl^-	15	0.42	
HCO_3^-	100	1.64	82
CO_2	6	0.43	