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Generating Interest Among Undergraduates Toward Research in Environmental Engineering by Incorporating Novel Desalination Technology-based Hands-on Laboratory Assignments

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Abstract

Undergraduate students were exposed to hands-on novel desalination laboratory experiments in an attempt to generate interest towards research in the broad field of environmental engineering and specifically in the field of water desalination. The laboratory exercises were designed to introduce desalination techniques, enhance their learning experiences, generate interest among them, and prepare them as potential researchers in laboratory settings. The hands-on experience of capacitive deionization (CDI) based laboratory experiments provided foundational and working knowledge of the CDI concept and allowed students to learn basic methodology followed in environmental laboratories to arrive at technical conclusions.

Students were given opportunity to desalinate water solutions using commercially available carbon aerogel fiber/paper electrodes at various conditions. Different parameters such as applied voltage, ambient temperature, initial concentration, flow rate, ion radius were varied and effects on desalination performance were observed. The teams were assigned one of these variables and asked to explore the effect its variation on desalination in using a semi-batch mode CDI experiment set up.

Students used conductivity meters to develop salinity vs conductivity calibration curves for a given salt type. Each team was asked to prepare and use their calibration curve to measure the salinity levels of 2 to 3 solutions of unknown salinity of the same salt. Each team was asked to adopt a basic CDI reactor and were provided with basic material, equipment and supplies and guidelines for the project. A salt solution was pumped through the reactors in a continuously re-cycled (multi-pass) mode. The conductivity was measured in a reservoir. Students were asked to do mass-balance calculations on total quantity of the salt removed using initial and final concentrations, and the volumes of the solutions used in their experiments. Students explored the effects of various operating conditions on desalination.

The hands-on experience focused on design-build-operate approach starting from preparation of solutions of varying concentrations, preparing calibration curves, adopting a reactor with a basic design and operating it under variable conditions exposed students to fundamentals of experimental research. Pre/post-activity surveys were conducted to measure the students' experiences on specific aspects of the laboratory assignments and their change of interest in environmental engineering. The results have been encouraging and provide deeper insight into the whole process.

This experience made a positive impact on students. General trend, based on pre/post activity surveys, shows that students are more interested in environmental engineering post activity and feel more confident about their abilities to solve real-world problems in water related issues. Students liked the format of group activities. Some of them are interested in pursuing a graduate degree and/or career in environmental engineering because project related activities provided them a good exposure and generated greater interest.

Introduction

Undergraduate civil engineering students usually are required to participate in a laboratory component of environmental engineering classes. It provides them opportunity to learn various measurement techniques for basic environmental parameters that are covered in introductory environmental engineering class. It is not common for students majoring in civil engineering to have a comprehensive exposure to environmental engineering and opportunities to implement and experiment with the knowledge gained in classrooms. However, it is expected that these engineering students will be able to manipulate materials, energy, and information in their professional roles. However, students must have a knowledge that goes beyond mere theory. Fundamental knowledge, traditionally gained in educational laboratories, provide a better base that is long lasting and easy to recall in future based on their experience and sensory memory. Learning styles vary person to person as discussed in many publications [*1-5*]. Since routine class lectures normally do not promote active learning and not every student can easily absorb and understand theoretical knowledge presented in this kind of class setting, hands-on laboratory based assignments usually are more effective in generating a greater interest among students [*6*, *7*]. The authors have been working to incorporate hands-on and laboratory-based experiments for introducing students to environmental engineering related research [*8*, *9*]. Laboratories are foundation of science based education in this century [*10*] and their use usually result in understanding concepts better. There are published studies that provide evidence in favor of student-centered hands-on active teaching and learning in laboratories [*11-15*].

When it comes to preparing future professionals of environmental engineering laboratory-based education should provide students understanding of techniques, instrumentation, operating procedures, and precautions that are necessary for deriving meaningful data-based conclusions. Students must be able to design their own experiments to get data required either for verification and/or modeling versus simply conducting experiments already designed for them to verify a concept learned in a class. This is the first step and foundation of conducting experimental research. This paper presents observations and conclusions from a study (as a part of an introductory environmental engineering course) focused on novel desalination technology to generate interest among undergraduates towards research in environmental engineering.

Course and Laboratory Background

CVEN 314 - Environmental Engineering, is a junior-level course in civil engineering at Louisiana Tech University. It is the only required course focused on environmental engineering that civil engineering students must take before they graduate. Usually, students take it in Winter Quarter of junior year. This course is designed to introduce students to the discipline of environmental engineering. In this course students are introduced to basic concepts and terminology required for environmental engineering practice and the role of environmental engineering in daily activities and quality of life. In addition, students are introduced to the theory of unit operations and processes most often used in environmental engineering, especially in water purification and wastewater treatment. Students learn to use basics of chemistry and mass-balance concept in various real-life situations including river systems and unit processes used in municipal treatment systems.

Starting winter quarter of 2015, laboratory component of this course was made more hands-on with inclusion of a wider range of assignments. The methodology adopted, process implemented and lessons learned in developing environmental engineering laboratory for this course to promote active and hands-on learning were presented at the *Second Mid Years Engineering Experience Conference Slump to Jump!*, as "Environmental Engineering Laboratory Development to Promote Active and Hands-on Learning" by the primary author [*8*]. During winter quarter of 2017-18, the primary author worked with fellow authors (doctoral students) to incorporate novel desalination laboratory assignments to generate research interest among undergraduate students towards general environmental engineering and specifically towards water desalination. The exercises were designed to teach basic laboratory methods and techniques essential for environmental engineering careers either as a practicing engineer or as a graduate student or professional pursuing research. The objective was to enhance their learning experiences in laboratory setting. The students were introduced to advanced level desalination experiments based on capacitive deionization (CDI), an emerging and novel purification and desalination technology for low salinity water.

Electrochemical Methods and Concept of CDI Desalination

Electrochemical methods such as electro-kinetics and capacitive deionization have been used in environmental engineering by authors for various purposes ranging from water remediation and purification [*16-20*]. The fundamental concept of CDI experiment is analogous to a capacitor and movement of a charged particles through electric field between capacitor plates (electrodes). Basically, the CDI is an electrochemical process where a solution flows between two parallel electrodes that have opposite charges because of a low applied DC voltage. The ions are electrostatically attracted to the electrodes and get adsorbed onto these electrodes with porous structure [*18*]. Carbon based electrodes like carbon aerogel, and other carbon-based electrodes have been used in CDI studies due to their highly porous structure, high surface area, good conductivity and stability. Water exiting from such an arrangement, also known as CDI cell, is relatively purer than water entering the cell.

Methodology

Intuitional Review Board Approval

Since this study involved students, appropriate approval from Intuitional Review Board of Louisiana University was obtained. Authors were required to get training on various aspects of social and behavioral research to complete a certification process. The completion certificates of these trainings, pre and post activity questionnaires and a detailed description of the research was submitted as a part of human-use-approval packet. It was carefully evaluated by the Intuitional Review Board before it was determined that the study met the requirements of exemption under 45 CFR 46.101(b) (2): Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior.

Project Introduction and Team Assignment

Students were allowed to work in a group of maximum two members per team and were free to choose their partners. One-member teams were also allowed. Doctoral students, who also acted as mentors for this activity, introduced basic concept of CDI desalination using PowerPoint presentations. Basic techniques of preparing solutions of various strengths, preparing calibration curves using conductivity and salinity, and measuring conductivity to calculate concentration of a saline solution were also demonstrated. As a first part of this study, students participated in a laboratory assignment in which they used a conductivity meter to develop their own salinity vs conductivity calibration curves for a given salt. Each team was asked to use their calibration curve to measure the salinity levels of 2 to 3 solutions of unknown salinity of the same salt.

Following their experiments, each team was asked to submit a formal report based on the collected data through Turnitin link posted on course management system – Moodle. In their reports, students were asked to provide background and the theory related to the measured parameters. The required format and components of the report were shared with students at the start of the quarter. The grading rubric was also provided ahead of time. Additionally, students were given detailed instructions about the report requirements in the course laboratory manual. One of the instructions was to include pictures of experimental setups and measuring devices used during their measurements. Also, students were asked to include pictures of their rough calculations and notes taken during laboratory sessions as appendices of the report.

Authors hoped that submission of a formal report complete with pictures of experiment setup taken during demonstration and measurements along with pictures of rough laboratory notes would demand greater student involvement. Authors weighed upon positives and negatives of up to two students per report such as enough work-load per team, opportunity for free loaders, students in a team of two taking turns for lab reports, and team dynamics.

Conducting Your Own Experiment

As a second part of this study, students were given opportunity to desalinate water solutions using commercially available carbon aerogel fiber/paper electrodes at various conditions. Some of the parameters that were available for students to study included effects of variation of applied voltage, ambient temperature, initial concentration, and flow-rate. Students were asked to choose two variables that they wanted to study and work with doctoral students to prepare experimental set-up. Students were put in a situation where they were asked to make decisions and conduct experiment accordingly to collect relevant data for them to analyze and include in their reports. Students were instructed to consider mass-transfer and do mass-balance on total quantity of salt involved in their experiments. Students used initial and final concentrations and the volume of the solution in their calculations to find out percentage of salt removed and salt removal capacity (mg of salt removed per gram of electrode) of electrodes used in their experiments.

Assessment

Students were informed about the purpose of the study in the class verbally. They were also informed that participation in the activity was optional. Only students who were interested in the activity without any reward, participated and were surveyed. The surveys were conducted anonymously to ensure confidentiality. The questions/statements were in multiple choice format with five options to choose from. Only one option was to be chosen for each question. The five options were different for different questions but had similar progression of positivity such as “strongly disagree” or “really low”, “disagree” or “low”, “neutral”, “agree” or “high”, and “strongly agree” or “very high”. The survey questions/statements are presented in Table – 1. There were 20 students enrolled in the course. All of them were either junior or senior based on civil engineering curriculum. Initially, 18 students participated in the pre-activity survey. However, only 17 students (85%) finally participated in the study and completed the post-activity survey. The pre-activity and post-activity survey questions/statements were exactly same.

Table-1: Statements used in pre-activity and post-activity surveys and responses in pre (a total of 18)/post (a total of 17) format. Class size was 20.

Options / **Statement**	**“very low” or “strongly disagree” (1)**	**“low” or “disagree” (2)**	**“neutral” or “no opinion” or “do not know” (3)**	**“strong” or “high” or “agree” (4)**	**“very strong” or “very high” or “strongly agree” (5)**
1. My interest in environmental engineering is -	3/2	6/3	5/7	3/5	1/0
2. My knowledge level in environmental engineering research is -	1/0	7/7	7/4	3/5	0/1
3. I am planning to pursue graduate study in environmental engineering -	9/6	3/3	4/3	1/3	1/2
4. I am considering possibility of a career in environmental engineering -	5/2	4/8	6/2	1/4	2/1
5. My interest in water desalination is -	3/1	6/5	3/7	5/4	1/0
6. I am aware of conventional water desalination techniques -	2/0	5/2	4/2	7/13	0/0
7. My knowledge level of capacitive deionization and electrode materials used in this process is -	6/0	7/5	2/4	3/8	0/0
8. My confidence to solve new problems in water desalination and quality challenges is -	4/0	6/5	4/3	4/7	0/2
9. My experience in hands-on activities in environmental engineering is -	3/0	3/1	3/3	9/10	0/3
10. My interest in discussion/collaboration-based lab assignments/activities is -	0/0	2/0	5/4	9/11	2/0

Hands-on experience of design-build-operate, starting from preparing solutions of various concentrations, calibration curves and operating the prepared CDI cell under variable conditions exposed students to fundamentals of experiment-based research. Students were asked to participate in pre/post-activity surveys for authors to measure specific aspects of their experiences and interests. Additional, feedback regarding the class and the project was solicited on the Course Objectives & Outcomes Survey at the end of the quarter. Students were asked whether project activities helped them learn - the course content better, to work with new people, and other engineering skills such as designing an experiment and analyzing the collected data to get meaningful conclusions.

Results and Discussion

The Experiments

Students chose to observe the effects of variation of applied voltage and variation of initial concentration on CDI desalination of a synthetic salt water solution. Students conducted experiments at two different applied DC voltages (0.6V and 1.2V) and compared the percent removal of salt (drop in salinity). Also, they decided to conduct experiments with 100mg and 400mg NaCl per liter initial concentrations to be used as feed solution to be deionized. Every other experimental conditions were kept same in all experiments. The experiments were conducted in a semi-batch mode with water continuously re-circulated between reservoir and the CDI cell (inlet at bottom and outlet from top) with peristaltic pumps. The conductivity of the water in reservoir were recorded automatically by a probe every other second for 5-6 hours. Some of the pictures of experimental setup and equipment used in student are reports provided in Figure-1.

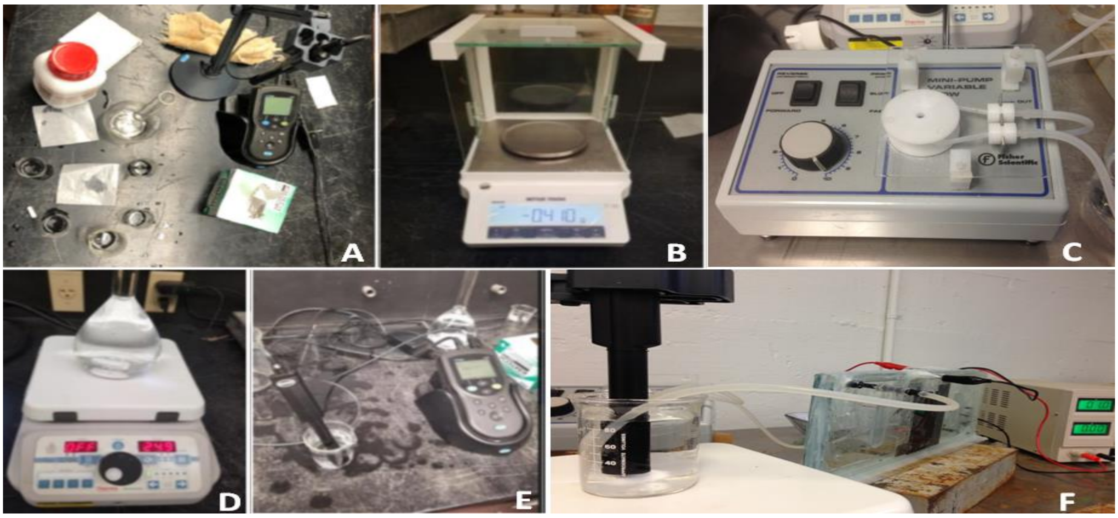

Figure-1: A sample of pictures of setup and basic equipment used by students and included in their reports. A – Conductivity meter and salt used during preparation of solution of varying concentrations. B – Digital weighing machine used for weighing salt amounts. C – Peristaltic pump used to re-circulate water between CDI cell and water reservoir. D – Prepared solution getting mixed using magnetic stirrer. E – Conductivity measurement of solutions used for calibration curves. F – Desalination in action using a CDI cell, reservoir, conductivity probe measuring and recording continuous data and DC voltage source for applied voltages.

Grading of Submitted Reports and Assessment of Students' Knowledge

Submitted reports were graded based on pre-determined criterion provided to students that included objective(s) of their experiments, description of their experimental method and setup, theoretical background, analysis of collected data as a part of results and conclusion. Students were asked to cite scholarly articles and research following standard formats. Majority of students seemed to follow the instructions and provide meaningful data analysis and discussion. They were able to provide conclusions that were supported by collected data.

Students were able to demonstrate active learning aptitude and ability to choose experimental variable and conduct experiments accordingly. Many students asked intelligent questions to doctoral students and showed a great interest in knowing more about desalination research. The 25% of the students (5 out of class enrollment of 20), either already submitted or are in process of submitting paperwork for dual enrollment in Master of Engineering with concentration in Civil Engineering. Three of these showed interest in pursuing research in environmental engineering area. Many students who liked the course and project activities were already committed to other areas of civil engineering as these areas were introduced to them early in sophomore year before environmental engineering. Early exposure to other courses played a big role for them to have higher interest over environmental engineering.

Also, there were students who did not like the level of chemistry needed for environmental engineering and for that reason were never motivated to pursue either professional career or academic degree in this specific field. Some suggested that there was a long "gap" between pre-requisite chemistry classes and this course. As a result, most of them forgot chemistry and struggled in the class during first few weeks of the quarter. In addition, there was a group of students that was already committed to other concentrations of civil engineering and for that reason, despite performing well in this course chose not to pursue environmental either as career or graduate degree. Students suggested that team-based course assignments helped them learn skills, such as delegation of responsibilities, working with new people, and meeting deadlines while collaborating with others. The course and project activities also made them aware of contemporary issues of earth and water pollution in different parts of the world. Several students expressed that they enjoyed project and course activities much more than they initially thought they would. Responses from both surveys (pre/post) are presented in graphical form in Figure-2.

Figure-3 below presents a summary of the questions from pre-activity and post-activity surveys. In most cases, students have benefitted from inclusion of hands-on laboratory assignment aimed to generate research interest among undergraduate civil engineering students towards environmental engineering. In one specific case, in response to one statement "My knowledge level in environmental engineering research is very low" percent of students responding dropped to "zero" from 17 as shown below. The results are presented after comparing same statements and options from pre-activity and post-activity surveys.

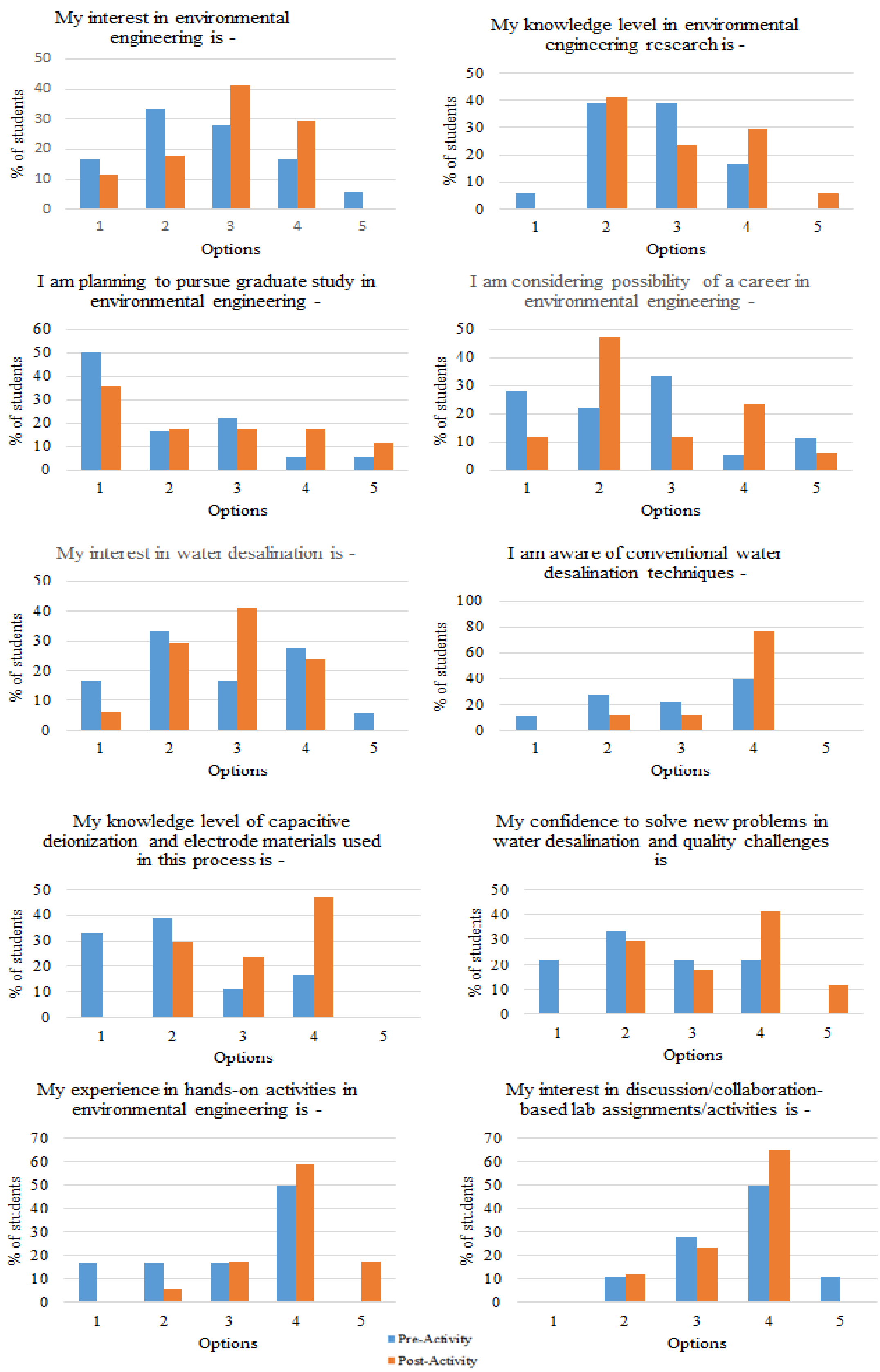

Figure-2: Response to pre/post-activity surveys by the participating students. There were 18 students who participated in pre-activity survey but only 17 participated in post-activity survey. Class size was 20. The options were categorized as 1 for “very low” or “strongly disagree”, 2 for “low” or “disagree”, 3 for “neutral” or “no opinion” or “do not know”, 4 for “strong” or “high” or “agree”, 5 for “very strong” or “very high” or “strongly agree”.

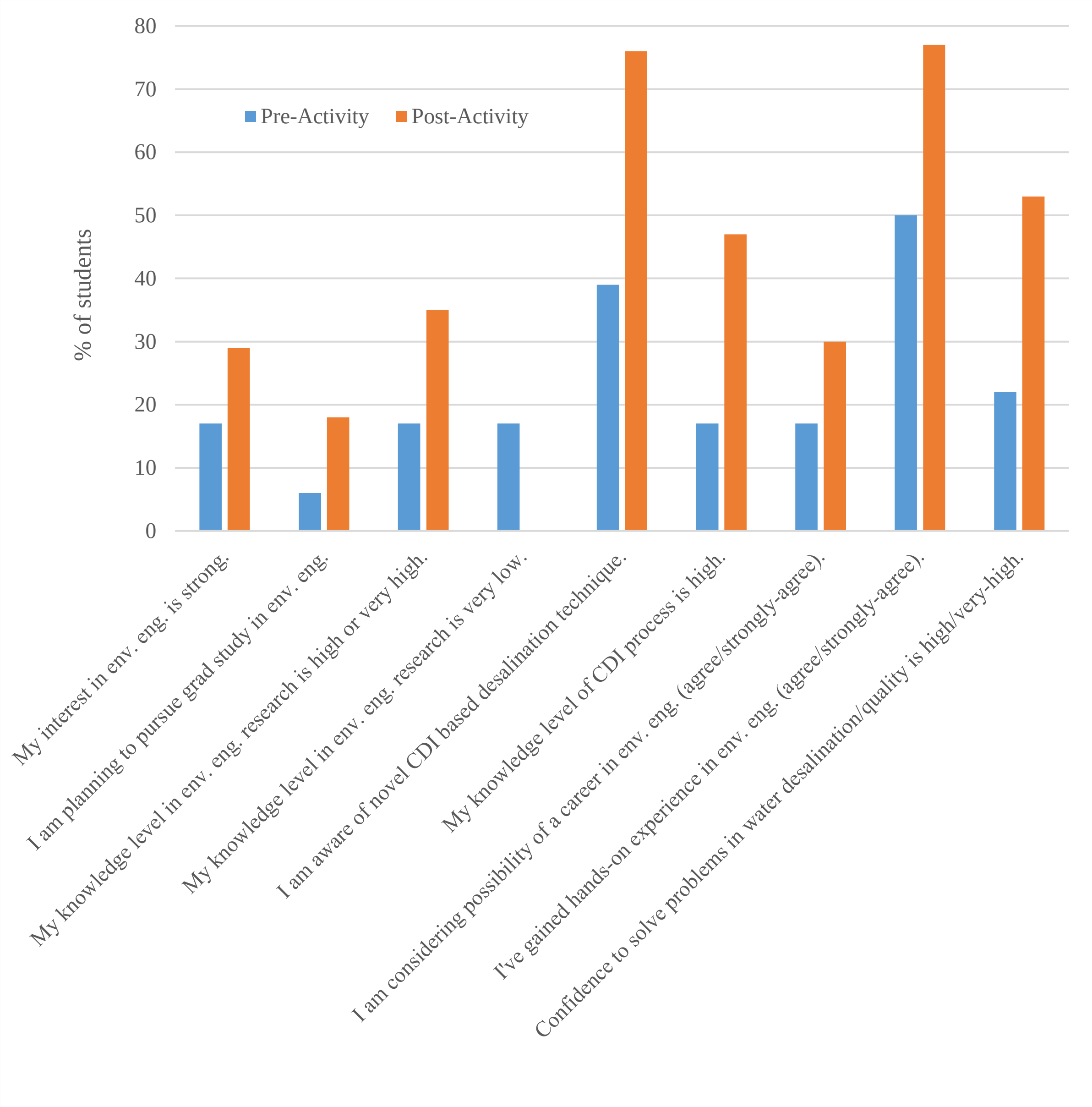

Figure-3: Summary of some of the questions from pre-activity and post-activity surveys.

Authors made some mid-way changes the way some of these project activities were being implemented and it resulted in some confusion the way students were asked to submit reports. This confusion made authors aware of the areas that were not planned and executed well and are needed to be planned better ahead of time. Some of the students missed the submission deadlines because of this confusion.

Lessons Learned

The lessons learned from this experience can be summarized as follows:

- Laboratory based exercises and assignments could generate research interest among undergraduate if designed with specific intentions.

- Students could be motivated towards research if given some freedom and opportunity to explore.
- Support from instructor(s) and teaching assistants is critical for students to pursue research which was not a required component of the course.
- The early exposure to environmental engineering in undergraduate degrees without a long gap between required chemistry classes, could motivate students to pursue graduate degree or a career in environmental engineering or the target area of laboratory-based experiments.
- Making changes mid-way in implementing project activities could result in a confusion and affect students' abilities to meet deadlines. A detailed course planning and clear instructions for project activities should be prepared ahead of time and any changes should be implemented in next term.
- Students show a greater interest towards environmental engineering when their laboratory experience is technically advanced but not confusing.
- Hands-on laboratory experience could boost students' confidence towards solving real problems of water quality and desalination.

In future implementations of the project, authors will scale-up the experiments and will widen the scope making them more general than keeping them to a narrow field of CDI desalination. While many positive experiences came out of the project, there is plenty of room for improvement. Forming a nationally competitive team to participate in Environmental Protection Agency sponsored People, Prosperity and the Planet (P3) Student Design Competition might be best accomplished through an extracurricular program, particularly due to the short time frame of the quarter system. I recommend narrowing the class project to a pick-and-place mechanism and using it as a springboard for an extracurricular team.

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