AC 2012-3158: A STUDENT CENTERED LEARNING LAB TO INCREASE MOTIVATION AND INTEREST IN ENVIRONMENTAL ENGINEERING

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Abstract

Problem based learning (PBL) is a well established student-centered approach which promotes application-based learning, enhances problem solving skills and fosters peer learning. This paper describes implementation of a PBL lab within a junior-level course on environmental engineering processes. The PBL exercise was an open-ended, two-hour lab, where student teams designed, built and tested a prototype water treatment system to achieve stated water quality criteria (UV transmittance and turbidity). Each team was given a scope of work that outlined the problem, objectives, design criteria, available materials, constraints, effluent quality testing protocol (using a synthetic influent) and evaluation criteria. Students were given no prior information about the lab, and the PBL lab was the first lab of the semester.

A multidimensional survey was developed and administered three times throughout the semester. Questions were designed to evaluate whether or not the PBL lab had a quantifiable effect on learner motivation (for the course and for environmental engineering), and self efficacy. Results indicate that the students enter the course as highly motivated learners (cohort motivation for course (out of 5): median=5, mean=4.32). This ceiling effects limits assessment of the direct impact of the PBL lab on learner motivation. The data do, however, suggest that learner self efficacy increased as a result of the PBL exercise. Evidence from post-lab student presentations supports this observation, with teams applying knowledge from previous classes to this new problem. The PBL lab was well received; students reported enjoying collaborating with their peers to develop a tangible solution to a *real-world* problem. Student feedback suggests the influence of the PBL lab may increase if learners had an opportunity to see the influent prior to construction. This study provides additional empirical evidence to encourage more widespread inclusion of PBL teaching/learning experiences into environmental engineering curricula.

Introduction

When undergraduate engineers leave the university environment and enter the workforce, they are often asked to solve complex problems in areas where they have limited knowledge or training. This requires the recent engineering graduate to: (i) apply concepts learned as undergraduates to these new situations; (ii) learn *on-the-job* through self directed efforts; and (iii) apply general hypothetico-deductive reasoning and problem-solving skills. The Carnegie Foundation has suggested that current undergraduate engineering curricula within the United States may provide insufficient preparation for engineering practice[1]. When evaluating the key traits engineers need for practice in the 21st century, the National Academy of Engineering (NAE) identified strong analytical skills, creativity, practical ingenuity, professionalism and leadership as being essential for success[2, 3]. The challenge lies in refining or developing engineering curricula to ensure engineering graduates develop these traits. Problem based learning (PBL) is one pedagogical approach that is gaining traction as a way to develop these traits and perhaps better prepare graduates for engineering practice[4].

PBL has its roots in medical training where students, working in small groups, are presented minimal information on a case and work to develop and test hypotheses that lead to correct diagnoses[5]. Patel and colleagues evaluated differences in learning approach and learner abilities of medical students in a PBL curriculum (PBLC) and a conventional curriculum (CC)[6, 7]. Students in the CC were exposed to clinical situations a year and half after being taught the theory, whereas students in the PBLC were taught the basic science within the context of clinical cases from the beginning of their medical training. Results from this study show that medical students in the PBLC were more likely to use hypothesis driven reasoning than students in the CC. Interestingly, experienced students (i.e., students nearing completion of the degree) in the PBLC integrated the basic science and clinical concepts in making diagnoses, whereas the experienced students in the CC relied more heavily on their recent clinical experience. The Patel study also suggests that the path taken by the PBLC cohort in developing a diagnosis was less direct than the path taken by the CC cohort, and more prone to incorrect diagnoses. These results suggest that learners engaged in PBL explore a wider range of potential solutions to a problem, and engage in increased and more sophisticated critical analyses (i.e, to parse data and distill important ideas from a large pool of information) when tackling a problem. While PBL encourages creative problem solving and reasoning coupled with self directed learning, it has been found to be most effective when learners can employ a solid understanding of theory as scaffolding for conceptual change[6-11].

The PBL process is well suited to engineering curricula considering its emphasis on finding creative solutions to problems having technical and societal constraints. Moreover, PBL aids in the transfer of knowledge and skills, as well as self-directed learning which may facilitate the innovation and life-long learning necessary within the community of practice[12-14]. It should not be surprising then that PBL and other student-centered pedagogical methods are being employed in a range of engineering curricula including chemical engineering, biomedical engineering and civil engineering[15-17]. Evidence from PBL applications in engineering curricula suggests that PBL based education may have a limited effect on student performance when measured using traditional assessment tools such as exams, but the data suggest a marked improvement in the ability of learners to embrace the complexity and challenge of *real-world* engineering problems[15, 16]. Yet, PBL is less well documented within environmental engineering despite the wealth of potential PBL opportunities.

We describe results from the implementation of a PBL exercise in a junior-level course for environmental engineering majors in a department of civil and environmental engineering. The course emphasizes the principles of chemical, physical, and biological processes relevant to environmental engineering to enable rational design of unit operations within the engineered environment and effective process assessment within the natural environment. The course traditionally follows a *lecture-lab* format, where labs on specific topics are conducted following the lectures on the content. In the semester that this PBL research was conducted, the class comprised 19 learners.

Design of the PBL Lab

As a pilot, we developed and delivered a PBL experience for the first lab in the course. The PBL lab was designed to engage students, get them interested in the course content and motivate them for the semester. While extensive technical content was intentionally not presented prior to the PBL lab, students were introduced to the range of processes they would encounter during the semester (e.g., coagulation, filtration, etc.). Students were provided no information on the content of the PBL lab and were asked only to bring a calculator, a ruler, writing implements and a notepad.

The PBL lab was adapted from a similar unit in the United States Air Force Academy's Field Readiness and Engineering Laboratory (FERL)[18], and presented as a prototype development and assessment exercise. Learners, working in teams of five (one team had four members), were required to design, build and test a water treatment system. The context of the problem was based on flooding events which occurred in rural Kenya. In this PBL lab a fictitious company is interested in developing point of use water treatment units which could be used during such emergencies. A memo was provided to each student from the vice president of engineering services which included the following: problem outline, basis of design criteria for the water treatment system (Table 1), design criteria and specifications (Table 2), list of available materials (Table 3) and prototype testing protocol (Table 4). Since no formal lectures had occurred in this course, students had to recall terms such as turbidity and UV transmittance from previous courses and apply them to a new context – design of an environmental process. The materials selection was intended to be representative of materials available in a developing country. Students were told that:

> *"Critical components for the systems along with engineering schematics, construction and startup instructions will be sent to Kenya with our field-service engineering team. The system should be designed so that it can be built and maintained locally. Field supplies and hardware for construction, startup, commissioning and operation can be procured in Nairobi and transported by truck to the village."*

Teams were given two hours to design and build their prototypes. This PBL lab was designed to build on the core requirements of PBL: the learning is student centered, occurs in small groups, the problem is presented before instruction or preparation and self directed learning is encouraged[9]. The course instructor, teaching assistant (TA), a graduate student, and staff member from the department were available as facilitators during the lab.

The influent for the PBL lab was made from food products and included products ranging from Quaker oats® and cocoa-laden cereal to vegetable oil (Figure 1) to simulate turbid, dirty, silty river water. Teams were not told what was in the influent until after the lab was completed or allowed to see the influent prior to the testing phase. This is an area where we intend to improve next year. Student feedback on the lab indicates they would have benefited from being able to see the influent prior to developing their design.

As part of the evaluation of this PBL lab, each team was required to give a post-lab 10-min presentation to the class outlining their basis of design, design strategy, construction approach and challenges, and organizational strategy. The teams were asked to retrospectively evaluate their designs and identify areas of improvement.

Teams were assessed on four, equally-weighted, criteria that were provided to the teams as part of the engineering memo. The criteria were: (i) quality of the design and related submittals; (ii) performance of the prototype relative to specifications; (iii)function and dynamics of the team; and, (iv) quality of the post lab presentation.

A Glimpse into the Undergraduate Engineer – from design to prototypes

All four teams designed systems relying on filtration. None of the systems, however, met the target effluent quality described in Table 2. The principal differences in the design related to the hydraulics of the filter, selection and order of *tanks* (buckets), and design of the filter bed. Two of the teams designed a multimedia filter using the coarse gravel on top and fine sand at the bottom. The other two teams elected to separate the coarse gravel into pre-filter. In the design submissions, all teams clearly articulated advantages of filtering out larger debris early in the treatment process (without having being formally taught this, yet). Some of the teams specifically noted applying Darcy's law to estimate how high the influent feed box needed to be to achieve the specified flow rate. This indicates that students applied concepts learned in earlier, introductory classes to this new scenario. One of the teams elected to build a small scale model using some of the materials and test different multimedia filter designs – i.e., *pilot testing*. Observation during the design process and submitted design documentation supports the evidence from prior PBL scholarship that suggests PBL exercises encourage students to synthesize and apply knowledge to new situations.

Overview of the Survey Instrument

A multidimensional survey was developed and administered three times in the semester – on the first day of class (*pre-lab*), again after the PBL lab (*post-lab*), and again at the end of the semester (*end-of-semester*). The goal of the surveys was to evaluate whether or not the PBL lab had a quantifiable effect on learner motivation and self efficacy. Motivated learners are more willing to dedicate energy towards learning material and concepts [19]. Self efficacy, according to Bandura[20], relates to how individuals perceive their capability to perform specific tasks.

The questions in each of the three surveys fall into one of four categories: team assessment questions, self assessment questions, evaluation of PBL lab and the class, and assessment of environmental engineering (Figure 2). The pre-lab survey comprised 13 questions and was primarily used to collect learner self assessments in the areas of experience, knowledge and skills within the context of environmental engineering, as well as career options currently under consideration. The post-lab survey comprised 21 questions. In addition to the questions from the pre-lab survey, the post-lab survey collected student assessments of team performance during the PBL lab. The end-of-semester survey comprised 17 questions - 9 from the pre-lab survey, 2 new questions for student assessment of self and team performance in the non-PBL labs during the semester, and 6 new questions aimed at enhancing University surveys for student assessment of the course materials.

Survey Results and Discussion

Analysis of the data from the pre-lab survey indicates that the 19 students in this class entered the semester highly motivated to take this course (median and mean scores (out of 5) were 5 and 4.32, respectively). This result creates a ceiling effect and limits direct evaluation related to how the PBL lab influenced student motivation. Students cited the importance of the course to their career plans and interest in environmental engineering as the primary factors motivating their interest in the course (Figure 3). When asked, at the end of the semester, what the impact of the PBL lab (1st lab) was in motivating students to learn the course material, 7 out of the 19 students scored it 5 (out of 5), 4 students scored it 4, 5 students scored it 3 and 3 students scored it 1; the median score is 4. Therefore, the PBL lab is as an important factor in cohort motivation for taking the course immediately after the lab and for having staying motivated for the course, as reported at end of the semester (see Figure 3 right panel).

Comparison of the data from the pre- and post-PBL lab surveys indicates that the PBL lab increased learner self efficacy by a statistically significant margin (p-value < 0.05). Students reported increased confidence in completing tasks based on material they had learned but may not have yet mastered (median scores out of 5: pre = 3, post = 4) and material they had learned and mastered (Figure 4). These data suggest that the PBL lab may be effective in increasing problem solving and critical thinking skills. Perhaps more interesting though is how the PBL lab appears to have influenced learners who reported lower self efficacies early in the semester. A significant increase in self efficacy is noted for these students (Figure 5). One should however, evaluate these data with caution considering the small sample size (n=19), leverage of a single data point, and the potential ceiling effect.

While these results are consistent with previous PBL research in engineering[16], a shortcoming of our research is the absence of a control group to quantitatively evaluate the PBL aspect of the lab to a prescriptive version of the same lab. A comparison of the reported student self efficacies immediately after the PBL lab (post PBL-lab) and the end of the semester indicates that these are not statistically different (Figure 4 – median value = 4, in both cases). This may suggest that the lectures and prescriptive labs conducted as part of this course following the PBL activity may do less to ameliorate learner self efficacy than the PBL lab. Again, the small sample size and ceiling effect limit using this as direct evidence of the beneficial impact of the PBL aspect of the activity, so additional, perhaps longitudinal, research is needed to quantify the benefits of PBL both within the classroom and laboratory environments. Overall the observational, anecdotal, and instrumental data in our study support more widespread evaluation of PBL and other constructive pedagogical techniques in environmental engineering curricula.

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Ingredient	Quantity
Cocoa Crunchies Cereal	390 g
Sodium Chloride	20 g
Calcium Carbonate	6 g
Vegetable Oil	300 g
Distilled Vinegar	230 g
Quaker Quick Oats	100 g
Yellow Food Coloring	8 drops
Red Food Coloring	20 drops
Mustard Seeds	85 g
Versa Clean Lab Washing Soap	15 g
Post Grape nuts Cereal	220 g
Lime Jell-O	100 g
Orange Jell-O	215 g
Tap Water	17 L

Figure 1: The influent water contained a mix of typical household products.

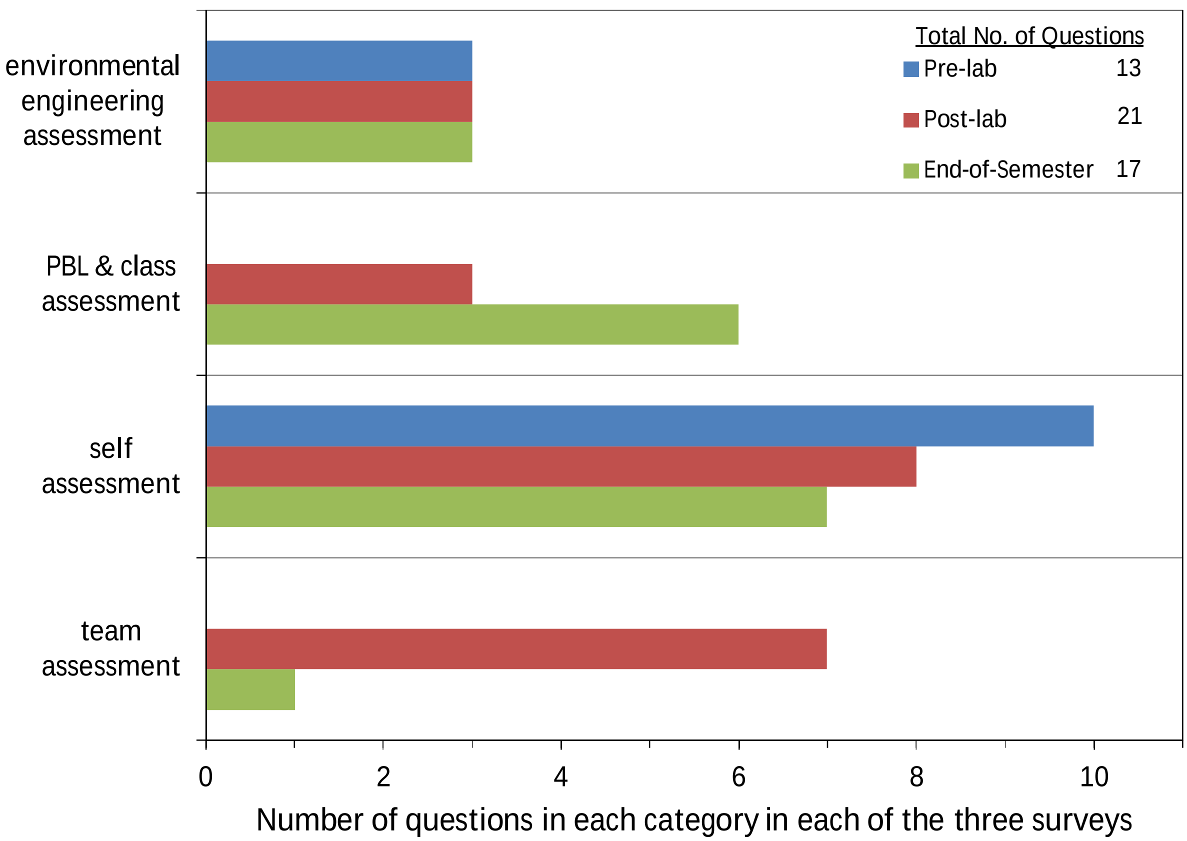

Figure 2: Classification of Survey Questions from Pre-lab (blue), Post-lab (red) and End-of-Semester (green) Surveys.

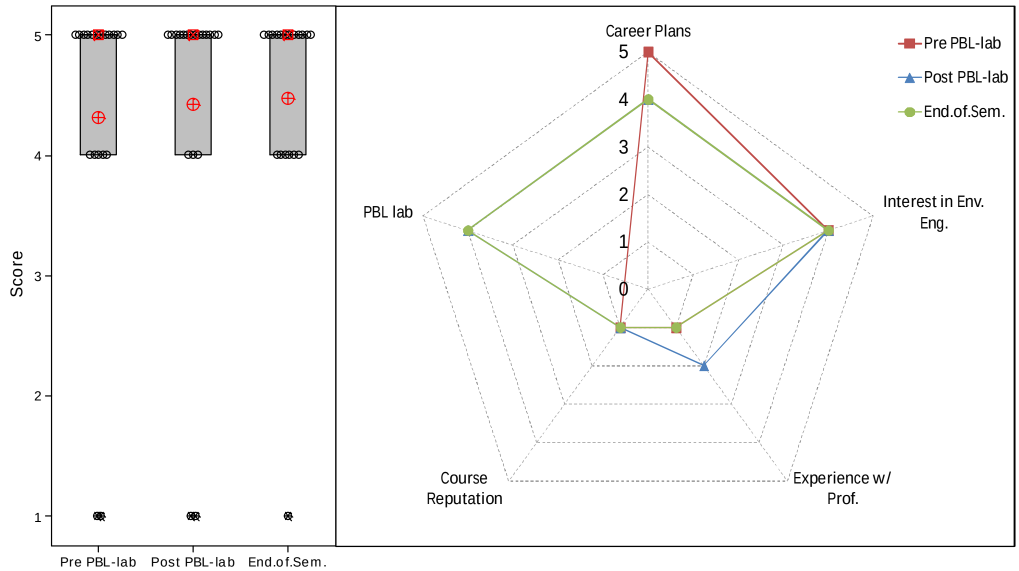

Figure 3: Left panel: Student motivation for the course at the beginning of the semester (Pre PBL-lab), immediately after the PBL lab (Post PBL-lab) and at the end of the semester (End.of.Sem.). Individual data points are shown using small black circles. Median and mean are indicated by red squares with cross and red circles with cross-hairs, respectively. Box extents indicate 25th (Q1) and 75th (Q3) percentiles. Right panel: Median scores for impact of factors on motivation. Each impact factor was scored independently on a 0 (not at all relevant) - 5 (extremely relevant) scale.

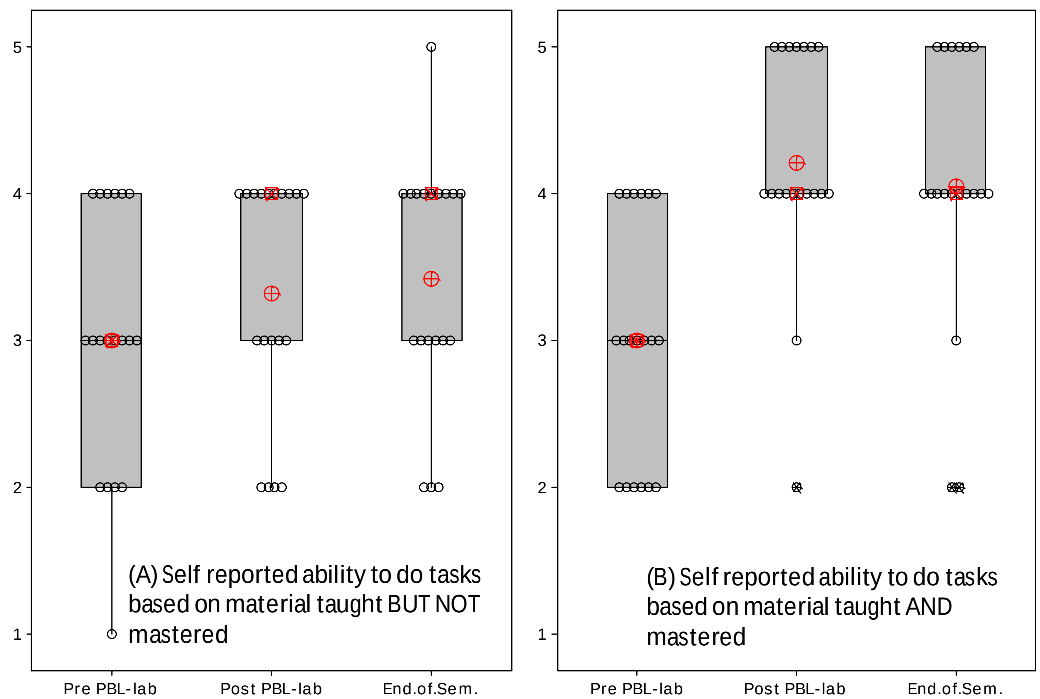

Figure 4: A comparison of learner self efficacy to perform tasks based on material they have been taught but not mastered (left panel) and mastered (right panel). Individual data points shown using small black circles. Median and mean values are indicated by red squares with cross and red circle with cross-hairs, respectively. Box extents indicate 25th (Q1) and 75th (Q3) percentiles, with whiskers extending to upper limit [Q3 + 1.5(Q3-Q1)] and lower limit [Q1 - 1.5(Q3-Q1)].

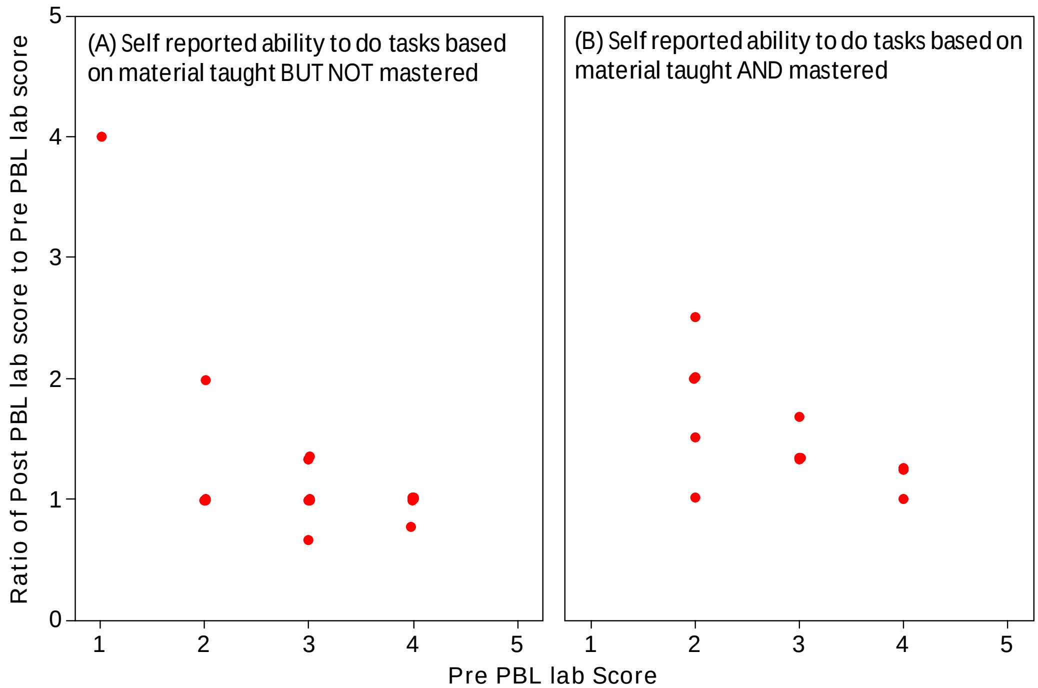

Figure 5: Measuring the impact of the PBL lab on learner self efficacy based on material taught but not mastered (left panel) and mastered (right panel). In both cases, the PBL has a significant impact on students who reported lower self efficacies prior to the PBL lab

Table 1: Water Treatment System - Basis of Design	
Influent Quality:	
• Turbidity	≥ 500 NTU
• UV Transmittance	≤ 10% (at 254 nm)

Table 2: Water Treatment System Design Criteria and Specifications	
Treatment Capacity:	5 gallons in 30-min[1] (10 gph)
Surface Loading Rate:	
• Minimum SLR	2 gallons per minute per square foot (gpm/ft^2)
• Maximum SLR	5 gpm/ft^2
Effluent Quality Requirements:	
• Turbidity	≤ 2 NTU
• UV Transmittance	≥ 50% (at 254 nm)
Physical Size Requirements:	
• Maximum footprint	8'x8' (64 sq.ft)[2]
• Maximum height	10'

Notes:

1. The system does not have to treat the water continuously (i.e., fed-batch operation is acceptable).
2. Complete system (including effluent storage must not exceed noted maximum footprint)

Table 3: List of Available Materials

Item(s)	Qty	Comments
Tanks • 5-gal • 3-gal	3 1	• Instructors will pour the influent all at once into one of the these tanks of your choice • One tank must be used to collect your treated effluent
Toilet Paper	1 roll	
Fabrics • Bed sheet • Cheesecloth	cut lengths	
Jute rope	~15 ft	
Clean water	1 L	• **Do not drink this water**.
Duct Tape	1 roll	
1-gal plastic bags	10	
First Aid Kit	1	• includes gauze pads, band aids, isopropyl alcohol, and bandage wrap
500 ml bottles	6	
Garden Hose (5/8”)	~20 ft	
Screens: ¼” & ½”	1 each	
2x4 wood pieces	assorted	• Pick up from *wood shop*
4’ x 4’ plywood sheet	1	
Nails:	assorted	• Located at common equipment station • Includes 2” – 4” nails
Natural Materials: • Sand • Gravel	as required	• A set of sieves is available at the common equipment station should you chose to use it
Tools & Accessories:	1 set	• Includes: basic tools, drill, quick-set caulk • Additional tools/equipment are available at the shared tools station should you need them

Table 4: Prototype Testing Criteria

General Notes on Testing:
• Inform the instructor once your prototype is constructed and you are ready to test it.
• Each system will be leak-tested with the clean water.
• If there are leaks and/or you are not satisfied with your prototype you have the option of requesting additional time to make modifications (document all modifications made).
 	
Overview of Testing Protocol:
• the instructor will pour the influent all at once into one of your tanks
• effluent sampling and analyses:
  o you will collect <u>3-effluent grab samples</u> when instructed to and
  o <u>2 composite samples</u> from your effluent collection tank
  o you will measure and note the turbidity and UV transmittance of the grab and composite samples