Incorporating “Real-world Experiences” into Undergraduate Environmental Engineering Design Projects: Design of Small-Scale Water Purification Units

J. A. Starke*, M. A. Butkus, M. B. Kelley, and M. Talbot
United States Military Academy

Department of Geography and Environmental Engineering
United States Military Academy
West Point, NY 10996

*Corresponding Author. (845) 938 – 3042 (phone), (845) 938 – 3339 (fax), bj2846@usma.edu
Abstract
The complete design process includes identifying a need or problem, recognizing constraints, identifying and developing courses of action, testing potential courses of action, selecting optimum courses of action, preparing the documents required for the design, managing the overall process, communicating the design, construction and testing. By linking design projects in our introductory physicochemical treatment processes course (taken by second semester juniors) and our senior capstone design course (taken by second semester seniors), we have addressed these design considerations. We require our cadet students to communicate with their customers, an illustrator and tradesmen; these are three forms of communications that are quite different from the traditional student-professor exchanges. Also, students must design under constraints, not because of the closed nature of the project but rather because of "real world" resource constraints: time to complete the project, a limited budget to purchase materials and labor, availability of materials, ease of construction, and balancing competing projects (in other courses). The first attempt at implementing this engineering design learning model occurred during the spring of 2001. Subsequently, we have incorporated an Army funded project into the design portion of these courses. The project is focused on the design of a small-scale, multi-barrier, water treatment device to be carried by the individual soldier. An overview of how this research project has been implemented into this multiphase learning model and lessons learned will be presented.

Introduction
The complete design experience includes identifying a need or problem, recognizing constraints, identifying and developing courses of action, testing potential courses of action, selecting optimum courses of action, preparing the documents required for the design, managing the overall process, construction and testing. In order to develop introductory level knowledge of common environmental engineering unit processes, students are often challenged with highly constrained problems that have one "right" answer. This learning model can be perfectly acceptable because it meets the intent – to provide an introductory level of understanding. However, by itself this "one right answer - textbook approach" cannot fulfill the curriculum level needed in engineering design. Several additional experiences, such as those identified above, are required to help students develop a more holistic appreciation for professional practice issues and to prepare them for the workplace. Such an approach may require more than one semester to achieve.

Students can gain an enhanced appreciation for the engineering design process in an engineering program curriculum model, which features an iterative design opportunity because problem solving is a process that students must experience iteratively. Such an experience allows for a period of design activity, a period of growth and reflection, and a follow up period of "higher level" design activity. Because troubleshooting existing processes is quite different than designing a new device or process, the follow-on design activity would ideally entail an advanced phase of the same project that involves troubleshooting flaws in their first design activity. In addition, this multiyear design project would allow for the assessment of teamwork and communications throughout the students' engineering program, not just during the last semester – which is essential for student development. Engineers in the field want to hire young engineers who have experience working with different groups of people and have hands on experience. Our
approach allows students to be evaluated on these skills while they work on the same project. This is one reason why the engineering design process is considered a key aspect of any ABET accredited program. Here at the United States Military Academy (USMA), we go one step further as engineering design concepts are also directly aligned with the USMA Academic Program Goals.

The Environmental Engineering Program, at the USMA, has integrated design in the curriculum, depicted in Figure 1, to address these professional practice elements via the following design experience goals. The design builds upon the linkage of Physicochemical Treatment Processes (EV401), Senior Design Capstone (EV490), and Independent Study (EV489).

- Challenge students with open-ended designs.
- Provide students with the opportunity to communicate technical information to tradesmen, skilled technicians (e.g. an illustrator), and the customer.
- Develop multiyear design projects that allow for growth between iterative design steps.
- Allow students to devise an experiment to test their designs, conduct the experiment, and analyze the success of their designs.

![Diagram](image_url)

Figure 1

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The Environmental Engineering Curriculum (Class of 2005)

The first of several design projects, aimed at achieving these objectives, was started in January 2001. Since then, we have integrated an Army funded research project into this learning model that includes input from different groups of students as well as faculty research. Our purpose herein is to discuss the methodology used to coordinate this multifaceted effort, student and faculty successes, and many of the lessons learned from these experiences.

Methodology

By linking design projects in our introductory physicochemical treatment processes course (EV401, taken by second semester juniors), our senior capstone design course (EV490, taken by second semester seniors), and student independent studies (EV489) we have addressed the design considerations discussed above and set a strong foundation for achievement of the outcomes that pertain to problem solving and communications. In these two courses, students iteratively design and build solutions to problems for a variety of customers including the Army. It can be extremely motivating for students to see their design built and used. This reinforces the iterative process of design, it affords the students to re-investigate some of their concerns, and it adds increased levels of experience and education by the same students to be incorporated into the same design. Because the students spend a significant amount of their total educational experience on one project, they may spend more energy to make it the best project possible. Since the students work on the project during their junior and senior years, there is both a reflective period and an iterative component to the project in which students grow as engineers and advance their designs.

We form the students into design groups and subgroups with roles that model typical design firms, a common practice in capstone design projects. As shown in Figure 2, the students are required to interface with the client, develop plans for construction including a list of materials, communicate, make design modifications during the construction phase, test the design, develop operational guidelines, and write design reports. The linkage between the customer and the student is essential for a real world type experience.

The Design Problem

“Design a prototype reactor that is capable of providing multi-barrier water treatment to soldiers serving under austere conditions and protects them across a range of nuclear, biological, and chemical (NBC) and physical contaminants”. Soldiers operating under austere conditions would utilize these portable devices in situations where they cannot be re-supplied via existing bulk water treatment and Army distribution doctrine. This is a very open-ended problem statement that requires considerable thought from defining the “challenge” water, the required physicochemical processes, size and weight, and the power requirements. Integrating all these components within the confines of one semester is unrealistic. However, this becomes manageable as the same students design subcomponents over the course of two semesters.
**Implementation**

There are 5 distinct groups that contribute to the overall design in various roles as depicted in Figure 2. Three of these are student groups. The historical accomplishments, current scope of work, and future plans are described below and are outlined in Figure 3.

**Faculty Research**
The faculty are investigating different aspects of water treatment technology to assist the student projects to deliver the suitable process design. The faculty serve as the subject matter experts (SME) to assist the students as they progress through their design. Faculty member effort is to bridge the gap between the students and the current status of published research and regulatory/industry practices. The students enrolled in EV401 are 2nd semester juniors investigating specific individual process aspects of the overall device. The scope of their work is guided by faculty and EV490 inputs. The students enrolled in EV490 are last semester seniors that serve to investigate the more difficult aspects of the design and serve to integrate the current investigations with the specific deliverables specified by the faculty.

**Student Research**
Primarily conducted independently, these investigations are based upon student and faculty advisor interest spawned from their first semester experience in this design process. The first phase included an evaluation of silver and iodine for use as a residual disinfectant in small scale water storage systems such as the Camel Bak®. The findings will be provided to students in EV490 to evaluate and, if chosen, incorporate a mechanism for delivery in the water treatment device. The future focus of faculty/student research is on minimizing the power requirement for...
UV disinfection. We will evaluate the influence of dissolved species on the efficacy of UV disinfection against viruses and protozoa. By improving the efficiency of UV disinfection, we can reduce the power requirements of the devices, which is an important consideration in outfitting soldiers of the future. To prepare for this future investigation, one student is independently investigating inactivation of a pathogenic viral surrogate. Inspired by initial work conducted during the spring of 2002, this student is learning to infect *E. coli* with MS2 coliphage and inactivating the virus with UV light. This input will be used to determine the required dose of UV light in the prototype design he is concurrently designing in EV490.

**Student Support**
The final group is the several agencies that support this project. This includes lab technicians, manufacturers, material vendors, and craftsmen that build the models.

**EV401**
Students have completed several pre-requisite courses, as shown in Figure 1, that serve as the baseline of their knowledge. A brief introduction to the overall concept and the philosophy of the iterative nature of design are presented at the beginning of the semester.

**Spring 2002**
Engineering students from the USMA class of 2003 were the first iteration of EV401 students incorporated in the design sequence as depicted in Figure 3. The students were specifically tasked to deliver a prototype reactor for the UV disinfection subcomponent. The purpose of these reactors is to maximize hydrodynamic efficiency of a single cell UV disinfection system. Because these test reactors have variable hydrodynamic characteristics, e.g. the number and type of baffles can be changed, future students will be able to use them to conduct tracer tests and disinfection experiments to determine optimal flow characteristics. There were 12 students enrolled in this course assigned in two groups. Each group was given an existing UV lamp to begin their design. Upon completion of the semester, students designed, constructed, and conducted preliminary tests on the hydrodynamic characteristics of their individual reactors. Consideration to the degree of mixing, minimization of stagnant zones, and protection from short-circuiting was emphasized.

**Spring 2003**
The current scope of work for Environmental Engineering students from the USMA class of 2004 is to investigate the implementation of adsorption or ion exchange to remove chemical contaminants prescribed in the “challenge” water. Students will investigate both processes in the laboratory via batch and flow-through experiments. Students will explore commercially available, off-the-shelf granular activated carbon (GAC) and ion exchange resins. The incorporation of these physicochemical processes will be evaluated at mid-semester to determine the best practice for the design. The second half of the semester will be used to incorporate these processes into the overall prototype design proposed by EV490.
This is the capstone engineering course in the curriculum for the students. Students have completed pre-requisite courses, as shown in Figure 1, that serve to increase their knowledge. A brief introduction to the overall concept of project management and engineering design submittals is presented at the beginning of the semester.
Spring 2001
The USMA class of 2001 began our foray in the environmental engineering program into individual drinking water treatment (backpacker and small home appliance) devices. Students began this experience by selecting commercially available, off-the-shelf individual drinking water treatment devices to evaluate. Students prescribed a “challenge” water based upon the potential use of the devices for Army soldiers under austere conditions and they designed an initial laboratory evaluation of the devices. Their constraints as they designed the laboratory evaluation included their resources (i.e., time, people available, instrumentation and equipment availability) and safety as they considered the evaluation of multiple contaminants across the physical, chemical (organic and inorganic), and microbiological realms. The student teams prepared a laboratory evaluation report of their findings.

From this experience, the students gained an appreciation for the capabilities of the various devices, the limits of their laboratory capability, and a number of quality control issues. They also learned of a “masking effect” of trying to put a number of different contaminants into one “challenge” water (e.g., the dissolved heavy metal contaminant—lead, sorbing to the turbidity contaminant—clay, and therefore being removed via a size exclusion matrix). One striking result was the tremendous capability to inactivate coliform organisms via UV light disinfection. The student teams designed a device for treating drinking water in the field for an individual or small team of Army soldiers. This was the basis for the class of 2002 students to address and finalize the concept design phase of the project.

Spring 2002
For the spring semester of 2002, we continued the experience in individual drinking water treatment devices, by selecting the two most promising devices identified in the spring of 2001, and adding a third device just recently marketed into laboratory evaluation project. The ten students, learning from the 2001 reports, redesigned the challenge water and the testing protocol. They analyzed and evaluated the capability of the three devices. As in 2001, the 2002 students wrote a laboratory evaluation report and incorporated their observations into a concept design. This group of students did a better job at assimilating the laboratory results into multiple treatment technology concept designs. Some issues not adequately considered were further refinement of the “challenge” water and associated testing protocol. The use of UV light as a primary disinfectant, the power (including source, duration and intensity) required, the need for a residual disinfectant for water stored (e.g., in a canteen), and the packaging of all of the required technologies into a constrained package (size and weight) remain to be addressed by the class of 2003.

Spring 2003
The current scope of work for Environmental Engineering students from the USMA class of 2003 is to evaluate the UV light disinfecting reactors that they designed and supervised construction of in EV401 (spring 2002). The goal of this evaluation is to begin to actually design the UV light reactor of the prototype treatment device at the design flow rate (another requirement to
determine) required for an individual Army soldier in the field. The senior design class will then pass this information (device flow rate, challenge water and the initial UV reactor configuration and size) to the current junior year physicochemical treatment class, providing “just in time” input to use in their design experience. Simultaneously, juniors enrolled in EV401 will evaluate the GAC and ion exchange resin requirements and will provide that design data to the senior capstone design class for their use in the prototype design.

The seniors will also consider the power requirement for the UV light disinfection process. Students will, “on their own” and in a “just in time mode,” learn about electrical power requirements and how to deliver the required power, compactly and efficiently to the device in the field. Assistance will be available to them via a Department of Electrical Engineering and Computer Science (EE&CS) electronics technician. Not only will the students grow in this new experience in a technical area out of their comfort zone, they will have to communicate with a technician who, while an expert in electronics, is unfamiliar with the use of UV light as a disinfecting process. The product of senior year capstone design experience will be to develop two prototype designs using different reactor configurations incorporating all the required technologies in a size constrained package to meet the needs of Army soldiers in the field.

Results and Assessment

This project has consistently produced significant contributions each semester. At the end of each semester of work, students have presented oral and submitted written reports of their work that have outlined their conclusions and recommendations. Their recommendations have served as the start point for the ensuing year’s scope of work. Furthermore, the laboratory data to refine the “challenge” water and associated protocol have been documented and serve to focus the student’s laboratory work. In addition, prototype reactors have been constructed to assist the students in integrating the entire prototype.

Our assessment reveals the process to be a success because students were exposed to many new facets of the design process. Students communicated with a client and craftsmen during the course of the design - forms of communication that were somewhat new to them. Based on assessment results, it appears as if the students grew from this iterative experience. Students have invested a great amount of energy as they are producing a model, not just an end of the semester report. This is evident in the creative solutions and quality models that have been produced.

The administration of the design connections between these two courses must be well thought out and synchronized between faculty. This has been revised based on the following lessons learned during the first cycle of this new learning model.

- The iterative nature of design must be stressed throughout the semester. (The instructor must ensure that the students have the “big picture”.)

- The instructor must ensure that students communicate regularly (biweekly during the construction phase) with craftsmen and students in other courses.
• The instructor should provide the students with grading rubrics, during the semester, to guide them through the design process.

• Assessment is vital throughout this process to measure progress and success.

The initial assessment is that this is a very powerful method to teach the design process on a real-world problem. The advantages evaluated by the faculty include:

• Each student will see different aspects of the same design project. As this accounts for a significant time of their educational experience, they will be more likely to invest more time into the project resulting in more ownership of the project by the students.

• Applicable to future careers as military officers.

• Creativity is allowed. Students and faculty are also afforded the opportunity to revisit design flaws or concerns in the ensuing semester or guide the other group through their experience that might have resulted in failure of the design. This also provides an opportunity to evaluate and critique their peers resulting in a higher end learning experience.

• Emphasizes the iterative nature of design.

• Increases the project management skills of the students by providing them with the opportunity to coordinate within their group, with other groups, with clients, and with faculty.

• Created a synergy as the students worked with faculty towards the overall integrated design by delivering their sub component.

Conclusions

Design is best taught as a series of integrated experiences. We believe that we have integrated and leveraged the skills of junior and senior environmental engineering students to provide them with a quality design experience. It has grown into a project that offers the students a concrete reason to invest a large amount of their academic time towards a common focus. The quality of their products, innovative and creative solutions, and satisfaction of their work confirms this assertion. The thirty-five different students that have participated in this project have experienced what design should be – an iterative and challenging, but overall rewarding experience.
Biographical Information

JEFFREY A. STARKE is an Instructor in the Environmental Engineering Program at the United States Military Academy. His current research interests include evaluation of the efficacy of iodine and UV as methods of disinfection for small scale water treatment systems. His teaching interests include physicochemical and biological treatment processes and water resources.

MARK TALBOT is an Instructor in the Environmental Engineering Program at the United States Military Academy. His current research interests include evaluation of the disinfection systems for water treatment utilities. His teaching interests include physicochemical and biological treatment processes.

MICHAEL A. BUTKUS is an Assistant Professor in the Environmental Engineering Program at the United States Military Academy. His current research interests include evaluation of the efficacy of silver and UV as methods of disinfection for small scale water treatment systems. His teaching interests include physicochemical and biochemical treatment processes and environmental chemistry.

MICHAEL B. KELLEY is an Academy Professor and the Program Director for the Environmental Science and Environmental Engineering Program at the United States Military Academy. His current research interests are in clarification processes for drinking water treatment. His teaching interests include project management, holistic design, and curricular integration.


