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A decentralized and onsite wastewater management course: bringing together global concerns and practical pedagogy

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ABSTRACT

This paper reports on the design, implementation, and results of a course focused on decentralized and onsite wastewater treatment in global contexts. Problem-based learning was the primary pedagogical method, with which students tackled real-world problems and designed systems to meet the needs of diverse populations. Both learning and course evaluations demonstrated that the course was successful in fulfilling learning objectives, increasing student design skills, and raising awareness of global applications. Based on this experience a list of recommendations was created for co-developing and team-teaching multidisciplinary design courses. These recommendations include ideas for aligning student and teacher goals, overcoming barriers to effective group-work, and imbedding continuous course assessments.

Key words | backward course design, cooperative learning, decentralized wastewater treatment, onsite wastewater treatment, problem-based learning, team-teaching

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INTRODUCTION

The lack of adequate sanitation for 2.6 billion individuals worldwide is a global concern. Solutions will require professionals who can learn from an international exchange of ideas, and have the background, and perspective to fully understand and implement appropriate management of water resources and environmental systems. Leaders in industry and academia must accept this as a training and education challenge and prepare to foster the necessary knowledge and skill set development for both practicing and future professionals. To address this challenge at the University of Washington (UW) a course was designed–*Onsite and Decentralized Wastewater Management and Reuse–Technology, Ecology, Policy and Appropriate Solutions*–that provided students with fundamentals of onsite and decentralized wastewater treatment and experience with real-world applications. This team-taught course employed problem-based learning (PBL) (Duch *et al.* 2001; Gijbels *et al.* 2005) and team-based methods (Michaelsen *et al.* 2004) within a course framework built around six primary learning objectives (see Table 1).

PBL and other active, collaborative teamwork methods were chosen because they have proven to be effective teaching and learning methods and are also more reflective of real-world applications (Halpern & Hakel 2003). Learning is enhanced when students solve open-ended problems, like those faced by practicing professionals. These activities help students deepen their knowledge, develop design skills that are transferable to professional circumstances, and enables them to solve problems on their own (National Research Council 2000). The course was taught for the first time spring quarter 2007. This paper highlights the main components of the course, the learning outcomes relevant for knowledge transfer of onsite and decentralized wastewater management, and the lessons learned from implementing such a course.

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Table 1 | Learning objectives

As a result of this course students will be able to:
1. Identify, define and be familiar with testing and reporting methods for: key wastewater characteristics; environmental impacts of wastewater; public health concerns associated with wastewater; current treatment technologies; and different wastewater streams
2. Locate and interpret existing policies and regulations for onsite and decentralized wastewater treatment. Distinguish important aspects of policies and regulations relative to designing and operating an onsite or decentralized system
3. Explain basic elements of a site evaluation that are critical for onsite and decentralized wastewater treatment systems
4. Provide details of basic elements, design criteria, and mechanisms of removal for different onsite and decentralized treatment and conveyance processes
5. Determine suitable operational management and maintenance schemes for onsite and decentralized wastewater treatment based on needs
6. Determine key design issues and factors that are important for the successful implementation of onsite and decentralized treatment technologies based on client needs and the desired effluent treatment level and effluent recycle method. Compare and select the most appropriate technologies to meet treatment needs for a given situation

METHODS

The development of this course was approached as a rational design process using Fink's (2003) "backward design" method. The first step was to identify course learning objectives (see Table 1). The next was to determine what the best evidence was that students had effectively mastered the objectives. Learning activities were then designed applying the principles of authentic learning assessment, wherein the learning activities in which students are engaged result in demonstrations(evidence) of knowledge gained. This type of assessment is considered an essential component of PBL (Gijbels *et al.* 2005). Learning activities included employing a hands-on method for ribbon testing soil texture, designing a drainfield, discussing ecological effects of wastewater constituents in small groups and discussing policy as a large group.

The course began by building students' knowledge of onsite and decentralized technologies, ecological impacts, and regulatory policies; helping them to create a discrete knowledge framework, which they would then apply in an engineering design. Six homework assignments and a midterm were used to foster learning and evaluate how well students were achieving learning objectives one through five. Students then applied that knowledge in a four-week long group project to achieve objective six. There were three projects that were randomly assigned to six project groups with two groups working on each project. The projects included: upgrading the sustainability of a sanitation system for a national park in China with 2,000,000 annual visitors; implementing an onsite treatment system for a green building on the UW campus that eliminates discharge to sewer; and comparing cluster versus individual onsite systems for a housing development on the waterfront of the Hood Canal in Washington State. Other important aspects of the course included: (a) a web site where students could access all course information including assignments, readings, and supplemental information (http://courses.washington.edu/onsite/); (b) bi-weekly guest speakers from a variety of professional backgrounds; and (c) team-teaching, wherein instructors worked closely together on all aspects of the course development and facilitation.

Design teams

Final project groups were assigned to ensure diverse design teams based on cultural background, year in academic program, technical background, and international experience to help ensure that project teams were in-line with the course goals. In Bingham & McCord's (2004) listing of research-supported suggestions for forming highly effective learning groups, they stated that groups "should be as diverse as the class membership will allow. The goal is to have groups large and diverse enough to contain members with the knowledge and skill to successfully complete the group assignments" (p. 87). Participation in teams was evaluated through peer evaluation techniques (Michaelsen & Fink 2004). Each group member divided 100 points among their group peers; the resulting breakdown was used as a multiplier for the project grade. A key aspect was that students had to provide reasons for the points they awarded to group members. These written explanations provided a basis for faculty interventions where warranted.

Pre-class preparation

One of the basic components of the course was a series of pre-class preparation (P-CP) assignments, due at the beginning of each class period. These were authentic assessment activities, designed to serve several purposes. The first was to assist students to learn directly from the readings by helping them identify important points and then to complete a short reflective writing exercise. The P-CP also helped students focus on what was important for the associated course period, giving students a head start in the cognitive learning process of attention, comprehension, and integration (National Research Council 2000; Halpern & Hakel 2003; Svinicki 2004). These activities promoted a level of comprehension of the essential information allowing case studies to be introduced and discussions to be held during class time wherein further structuring and elaboration could take place.

Assessment

Several classroom assessment techniques (Angelo & Cross 1993) were employed to determine how various aspects of the course were working and whether adjustments needed to be made. Midway through the course, an outside evaluator conducted a small group instructional diagnosis (SGID), as well as a follow-up last class interview (LCI) at the end of the quarter. The SGID provides a means to collect data at mid-quarter and provides students an anonymous method for feedback. Through coursework student learning can be evaluated, but not necessarily how well the student and teacher are aligned, or what teaching methods the students find most beneficial (Wulff 2005). The SGID helps to ensure that a course is relevant to students' interests. The timing is critical to ensure feedback is obtained while there is still time to address it. The standard SGID protocol asks the students to answer two basic questions: what is helping them to learn in the course; and what areas should be improved. Consensus topics are discussed in order to determine where, and if, consensus can be reached among all the students. The LCI follows up at the end of the quarter to evaluate whether students felt their mid-quarter concerns had been addressed. The SGID and LCI are important components of a continuous improvement cycle. At the end of the quarter, data was also collected through the university's instructional assessment system (IAS). Data from each of these assessment methods were triangulated and compared with the evaluations of student learning to develop a clear understanding of where refinements could be made.

RESULTS AND DISCUSSION

Mid-term analysis of the learning assessment data and SGID results suggested that the overall course design was working as planned. Students' were developing the intended knowledge of course material and significant gains were being made in how they approached open-ended, real-world onsite and decentralized problems. However, early data also indicated that several bugs still needed to be worked out. Adjustments were made and by the end of the quarter evidence provided by the LCI, IAS and other metrics suggested that problems with course design were alleviated. At the LCI students expressed the perception that positive improvements had been made to the course based on their SGID feedback.

Student diversity

Having students work on open-ended problems, applying tools gained during their university tenure, was intended to better develop design skills to be utilized in their professional careers. The course was designed and offered as an undergraduate course, fitting into the engineering curriculum in the final quarter of the senior year. However, half of the students that enrolled for the course were graduate students and 15 percent of the students were from other majors. Many of the graduate students had bachelor's degrees from science departments other than engineering. This diversity turned out to be a strength in that the students brought different experiences and backgrounds from which everyone in the class could cooperatively experience and benefit, however, that cooperation was not automatic. Opportunities for collaboration were structured into the course with the small and large group discussions and the design project groups. Student comments from the SGID included "interesting make-up of students–exposure to different viewpoints and backgrounds". Some graduate students found diverse academic experience to be a weakness however, in that they did not find the course challenging enough. Based on this, in the future the course should be offered as a joint undergraduate/graduate course, but there should be an extra learning component for graduate students by increasing their mentoring roles in group projects. Based upon the final evaluation, projects benefited from the diverse make-up of complementary technical skill sets and diverse cultural and disciplinary viewpoints.

Course curriculum–learning objectives

An understanding of the basic concepts in Objective 1 was an important first step in building a conceptual framework that other objectives could build on. As explained in the report, *How People Learn* (National Research Council 2000), "To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application" (p.16). Non-graded methods such as class discussions and P-CP were built into the course design to monitor the development of fundamental knowledge.

The learning activity designed to achieve Objective 2 entailed each student researching policy and regulations for a different US state or protectorate. Regions were assigned to ensure an interesting diversity of regulations helping students understand the wide range of policies; these were then discussed during class time. This was successful in that the students had to research the information on their own as professionals would, and helped them to understand diversity of regulations. When the discussion ended, students were still engaged and commented that the 50 minute class time was not sufficient.

Ecological concepts including soil treatment mechanisms and impacts of wastewater to water bodies are key to understanding Objective 3. However, SGID responses to the question, "what is not helping" included, "ecology is being short-changed". Although there were regular discussions about ecological concepts, due to the diversity of students' backgrounds and goals, some students wanted to focus more exclusively on ecology. Feedback from the SGID provided an opportunity to make resources available, from a wastewater reference library and through the course website, for individual students based on their learning desires. This was one example of the potential inherent in gathering student feedback early enough to respond appropriately, and to create better alignment between students' goals and the goals of the course.

In evaluating learning Objective 4, it was apparent that students did not initially have an adequate understanding of nutrient removal. This evaluation was based on a P-CP asking students to balance an alum phosphorus precipitation reaction and describe mechanisms of nitrogen removal in a septic tank. The P-CP provided a method to alert instructors when students did not understand concepts introduced in classroom presentations or readings. Following the nutrient removal P-CP it was discussed in class, the solution was posted to the website for further review, and nutrient removal was included in the subsequent homework assignment. This was effective, and through the SGID students requested that more solutions to the P-CPs be provided.

The long-term success of decentralized systems requires an operational management and maintenance plan, as covered in Objective 5. Throughout the quarter how to determine appropriate management was addressed through ongoing discussions. Guest speakers included a representative of the US Department of Health addressing regional and national concerns, and the author of a United Nations Environment Programme (UNEP) report on determining appropriate technologies and management for international applications. Class discussions included US Environmental Protection Agency guidelines for management and the unique system of management in Japan.

Everything learned during the first half of the quarter was integrated and applied in final design projects to meet Objective 6. Application of knowledge in the design projects brought students to a higher level of learning, and allowed the instructors to gather good evidence for evaluation purposes. Prior to project assignments SGID responses included, "not enough design." To some students this meant they wanted to focus more on big-picture, qualitative aspects, others wanted more detailed, equation-based problems. P-CP comments indicated that the majority of students in the class did not have a full comprehension of what design meant, a process to go about it, or group dynamics of a design team. As Dym (2003) argued, "Design has been identified as the distinguishing mark of the engineering profession. However, both faculty and practitioners continue to be concerned that design is neither properly taught nor adequately presented in engineering curricula" (p. 5). It was evident from student comments that what design is, and how you acquire knowledge to apply in more complex problems, needed to be more clearly explained. Prior to assigning group projects a generic engineering design methodology was presented. The solving of a rubrics cube was used to present the information as a tangible framework that students had prior experience with (Figure 1). Design variables such as public health concerns, economic situation, regulations, operations and maintenance, and intended reuse of effluent were each represented as a cube in the puzzle. The problem solving methodology would then be applied to determine final design solutions that meet the clients' needs. How to work most effectively in teams was also discussed at the same time. Students successfully demonstrated their mastery of all six learning objectives in the final projects. At the time of the LCI students expressed that their desire for more design had been met and comments from the IAS question, "what aspects of the class contributed most to your learning" included, "applying engineering knowledge and design to real-world scenarios" and "to do a real design for [the] final project."

Course curriculum–individual activities

Pre-class preparation

Technologies employed in this field range from composting toilets to large urban buildings with membrane bioreactors and onsite water reclamation. Technologies need to be considered in the context of local regulations, management and maintenance, cultural preferences, economic situations, and ecological impacts. As students were only in the course for ten weeks, very conscious, deliberate decisions were made about what fundamentals students needed in order to address real-world problems. The amount of reading students were assigned was intentionally restricted, but students were held responsible for learning it. The P-CP drove this learning process, which ultimately allowed more material to be covered in a manner that students were able to comprehend and absorb. Following completion of the P-CPs key concepts of the subject matter were familiar to students, providing a stepping stone for the lecture material

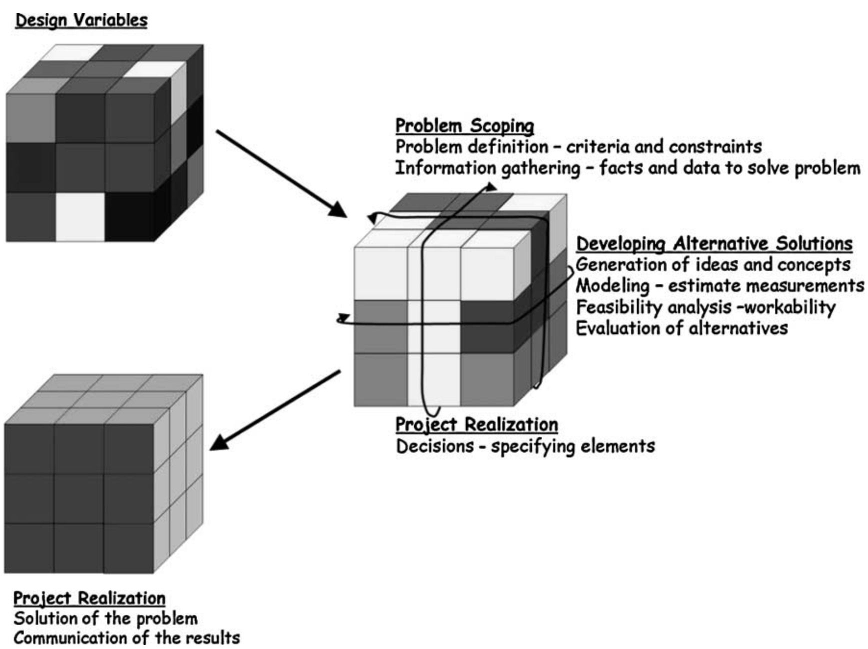

Figure 1 | Problem solving methodology to arrive at successful final engineering design (compiled from Atman *et al.* 2007).

and placing more of the learning responsibility on the students. Students were also more able and willing to share their perspectives during class time, making class more interactive. This was in contrast to the standard model where all readings and everything students learn has to be covered during class time. This traditional approach greatly limits class discussions and other active forms of learning.

The approach was successful as indicated by the SGID response, "instructors are well-prepared and cover a lot of material" and the IAS comment, "there was always plenty to consider in class and out of it, papers, class and class preparation always required high level thinking." However, during the SGID students were not able to come to a consensus on how they felt about the P-CP. Comments ranged from, "they help you know the key points you should be grasping", to "too tedious....we go over them anyway." In the analysis of the IAS data at the end of the quarter results showed that the majority of students viewed the P-CP as important for their learning. As one student commented, "the pre-class prep (even though I resented it) helped me keep on top of the topics/coursework." Many students also felt the P-CP was too much work once the final design project was underway. Adjustments will be made to the course syllabus in the number and frequency of the P-CP assignments, but the evidence gathered clearly shows the effectiveness of this learning tool.

Team cohesiveness

Feedback mechanisms were implemented to monitor and manage team process. Instructors met with groups for project updates including how each member was contributing, and to provide feedback. It was apparent during these meetings when groups were having difficulties. For example, one group needed to first consider alternatives before forging ahead on one design. Another was investing too heavily in the analysis of each alternative and needed a more efficient selection process. Teams also completed a trial evaluation of peer participation that provided feedback while there was still time to modify behavior and for instructors to intervene and alleviate problems (see Michaelsen & Fink 2004). In all groups except for one the peer evaluation process helped group members contribute in a fair and equal fashion. In the exception, it alerted instructors that intervention was necessary.

Guest speakers

Guest speakers helped introduce students to the diversity and complexity of real-world problems, ranging from government law and regulations to the design of treatment wetlands. A Roundtable with Industry event with a panel of five professionals was also held. The range of panelists included the president of a non-profit working on sanitation in multiple countries to the president of the national onsite member association (NOWRA). Panelists gave a brief presentation on a specific area from site evaluation to alternative systems and then the panel was opened up for questions from the audience. The Roundtable was held following the assignment of group projects. This allowed students to ask panelists questions specific to their projects and gave them a real-world problem to consider in the context of what they learned. The P-CP for the Roundtable resulted in an interactive and engaging discussion between students and professionals. On the end-of-term IAS course evaluation the students rated the guest speakers and the P-CPs as the two most important learning activities. A key to the success of the guest speakers was their integration into course objectives and goals. Prior to presentations guest speakers reviewed the course website, discussed course goals and objectives with instructors, and reviewed the P-CP that prepared students for their presentations.

Website

SGID responses to the question "what is helping" included "website is very helpful" and, "it is very organized, has lots of resources, it is a good road map for the class." However, the students also agreed that the "website organization could be improved." In the IAS course evaluations the students continued to praise the quality and usefulness of the material, as well as provided suggestions for improving the functionality of the website. This illustrates the difficulty of making a large amount of information available in a readily accessible fashion. The students' comments will be used to improve the accessibility of future course websites.

Benefits of team-teaching

Data demonstrated that the students gained a great deal of knowledge from this innovative course, yet some of the most important learning was achieved by the instructors themselves. Typically, team-teaching manifests as a disjointed series of discrete class sessions with different instructors lecturing at different times with little overlap of topics and often no integration of pedagogies. The main reason the team-teaching approach worked for this course was that the team spent a significant amount of time well ahead of the course developing objectives and approaches. From the very beginning the intent was to totally integrate the teaching process to facilitate the overall pedagogy. To develop a truly integrated course with more than one instructor, an academically diverse student body, and guest speakers with a broad range of expertise, these discussions had to take place.

In addition to the development of a well integrated course, it was also a goal to explore more effective teaching methods. In this effort the team included an instructional consultant, whose expertise was extremely important in key integration issues and facilitating an approach to the course. Through this process common understandings and a shared rationale for the course were developed, no matter which instructor led the class it had consistency and connection with the other's efforts. Another important factor in the success of this course was that both instructors shared a passion for the subject and awareness of how important it is on a national and global scale. By having two instructors feel this way and reinforcing each other's commitment, it was more meaningful to the students and had a stronger affect on them. Thus, team-teaching can provide an element to effective teaching that cannot be done as well by a single instructor, but it has to be done in a cooperative and coordinated way.

CONCLUSIONS

If the worlds' water resources and environmental systems are going to be effectively managed, consideration for how students learn to think about and solve problems is essential. A cadre of management professionals with current knowledge and broad perspectives is requisite for integration and implementation of an expanding array of technologies. This course is one model for the kind of teaching and learning necessary to build that professional cadre. Based on this experience, the following recommendations are provided for effective teaching and learning.

- *Course design*. Employ a logical approach to course design. The "backward design" method ensures that learning evaluation is tied directly to the learning objectives.
- *Pre-class preparation*. Preparing students for class time helps students focus and reflect on their reading. Benefits include increased cognitive development, motivation to complete reading assignments, and a method for ongoing assessment of student learning.
- *Limit content*. Focusing on key fundamentals provides students with a solid knowledge base to later access and build upon. Covering material in class is not equivalent to learning material.
- *Formative evaluation*. Evaluate teaching effectiveness and alignment with student-based learning. Implement evaluations with adequate time to modify or address any necessary changes.
- *Design process*. Teach students what design means and how to approach it before asking them to work on a design project.
- *Learning teams*. Form diverse design teams to increase learning from complementary skill sets and aid in development of design project skills. Promote accountability of individual members.
- *Course expectations*. Clarify expectations early and often. If students understand how learning fits into the progression and relevance of learning objectives, they will be more fully engaged.
- *Cooperative learning.* Engaging students with interactive teaching and learning helps ensure a high level of understanding, retention of learned information, and a greater potential for transfer to subsequent courses and professional lives.
- *Team–teaching.* A collaborative approach to team-teaching provides students with a diversity of expert perspectives within a course framework that facilitates conceptual integration.

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