PROJECT REPORT

Brownfield Action: Dissemination of a SENCER Model Curriculum and the Creation of a Collaborative STEM Education Network

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Abstract

Brownfield Action (BA) is a web-based environmental site assessment (ESA) simulation in which students form geotechnical consulting companies and work together to solve problems in environmental forensics. Developed at Barnard College with the Columbia Center for New Media Teaching and Learning, BA has been disseminated to ten colleges, universities, and high schools, resulting in a collaborative network of educators. The experiences of current users are presented describing how they have incorporated the BA curriculum into their courses, as well as how BA affected teaching and learning. The experiences demonstrate that BA can be used in whole or in part, is applicable to a wide range of student capabilities and has been successfully adapted to a variety of learning goals, from introducing non-science-literate students to basic concepts of environmental science and civic issues of environmental contamination to providing advanced training in ESA and modeling groundwater contamination to future environmental professionals.

Introduction

Brownfield Action (BA) is a web-based, interactive, three-dimensional digital space and learning simulation in which students form geotechnical consulting companies and work collaboratively to explore and solve problems in environmental forensics. Created at Barnard College (BC) in conjunction with the Columbia Center for New Media Teaching and Learning, BA has been used for over ten years at BC for one semester of a two-semester Introduction to Environmental Science course that is taken each year by more than 100 female undergraduate non-science majors to satisfy their laboratory science requirement. BA was selected in 2003 as a "national model curriculum" by SENCER (Science Education for New Civic Engagements and Responsibilities), an NSF science, technology, engineering, and mathematics (STEM) education initiative. The BA curriculum replaces fragmented, abstract instruction with a constructivist interdisciplinary approach where students integrate knowledge, theory, and practical experience to solve a complex, multifaceted, and realistic semester-long interdisciplinary science problem. The overarching themes of this semester are civic engagement and toxins, focusing on toxification of the environment, pathways taken by environmental toxins, and the impact of toxins on the natural environment and on humans. Readings that have been used to complement teaching using BA include Jonathan Harr's *A Civil Action* and Rachel Carson's *Silent Spring*.

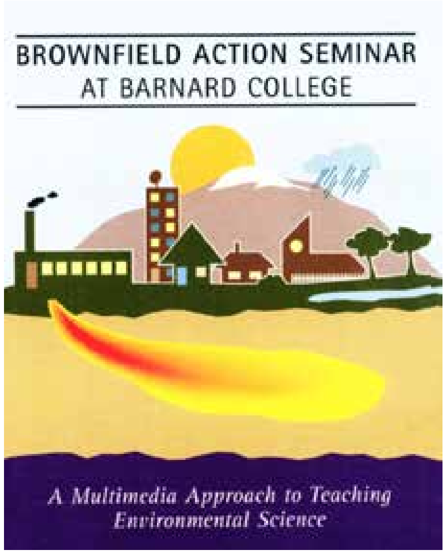

FIGURE 1. Call for a Brownfield Action Seminar using the Brownfield Action logo that shows a contaminant plume from a factory migrating in the saturated zone of an aquifer.

The pedagogical methods and design of the BA model are grounded in a substantial research literature focused on the design, use, and effectiveness of games and simulations in education. The successful use of the BA simulation at Barnard College is fully described in Bower et al. (2011). This article describes multiple formative assessment strategies that were employed using a modified model of Design Research (Bereiter 2002; Collins 1992; Edelson 2002), culminating in a qualitative ethnographic approach using monthly interviews to determine the impact of BA on the learning process. Results of these ethnographies showed at a high confidence level that the simulation allowed students to apply content knowledge from lecture in a lab setting and to effectively connect disparate topics with both lecture and lab components. Furthermore, it was shown that BA improved student retention and that students made linkages in their reports that would probably not have been made in a traditional teaching framework. It was also found that, in comparison with their predecessors before the program's adoption, students attained markedly higher levels of precision, depth, sophistication, and authenticity in their analysis of the contamination problem, learning more content and in greater depth. This study also showed that BA supports the growth of each student's relationship to environmental issues and promotes transfer into the students' real-life decision-making and approach to careers, life goals, and science (Bower et al. 2011).

BA is one of a small but growing number of computer simulation-based teaching tools that have been developed to facilitate student learning through interaction and decision making in a virtual environment. In STEM fields, other examples include CLAIM (Bauchau et al. 1993) for mineral exploration; DRILLBIT (Johnson and Guth 1997) and MacOil (Burger 1989) for oil exploration; BEST SiteSim (Santi and Petrikovitsch 2001) for hazardous waste and geotechnical investigations; Virtual Volcano (Parham et al, 2009) to investigate volcanic eruptions and associated hazards; and eGEO (Slator et al. 2011) for environmental science education. These virtual simulations give students access to environments and experiences that are too dangerous, cost-prohibitive, or otherwise impractical to explore (Saini-Eidukat et al. 1998). Through directed role play they also provide opportunities for social interaction and student inquiry into the human element of technical analysis and decision making (e.g., Aide 2008).

What makes the Brownfield Action SENCER Model Curriculum unique among these STEM online simulations is that it includes a significant component of engagement with the civic dimensions of environmental contamination, interwoven with the technical investigations being conducted by the students. The BA simulation is also unique in that it has been disseminated to ten colleges, universities, and high schools, and a collaborative community of users has developed. To the best of our knowledge, BA is the only SENCER national model curriculum with a network of faculty collaborating in a community of practice. Moreover, this network has adapted the original simulation and its related products for use with a widening diversity of students, in a variety of classroom settings, and toward an expanding list of pedagogical goals. This paper documents the experiences of ten teachers and professors (in addition to those at Barnard College) who are using BA to improve student learning and teaching efficacy, to improve retention in the sciences, and to increase student motivation and civic engagement. All of these teachers and professors have shared their experiences, course materials, and curricula developed using the BA simulation in their courses, and the evolution of this collaborative network has now begun to define the direction that BA is taking. Currently the network consists of environmental scientists, an environmental engineer, a sociologist, geologist, GIS specialist, a smart growth and landscape architect, and high school science teachers, all sharing the goal of teaching science from the perspective of promoting civic engagement and building a sustainable society. Team members have developed course content specific to their individual fields of expertise and have made their course materials available to the community. The goals of this collaborative network also include telling the story of the dissemination of BA and thereby encouraging the dissemination of other successful SENCER model curricula. Ongoing efforts are being made to expand the BA network, especially among the hydrogeologic, brownfield, and environmental site assessment community. The BA SENCER Team has also begun to develop BA for use in online education.

The purpose of this paper is to present the collective experiences of the college and university faculty and high school teachers who have incorporated the BA simulation and curriculum into their courses. The experiences using BA reported here demonstrate how the BA simulation can be adapted for use, in whole or in part, for a wide range of student capabilities, and the authors describe how BA affected student learning and satisfaction. The descriptions that follow include applications of the BA simulation to environmental instruction at the high school level (Liddicoat, Miccio, Greenbaum), to the fundamentals of hydrology and environmental site assessments at an introductory to intermediate undergraduate level (Bennington, Graham), and to training both undergraduate and graduate students in advanced courses in hydrology and environmental remediation (Lemke, Lampoousis, Datta, Kney). Although many of the applications reported here apply to courses in STEM curricula, BA is not restricted in its utility to teaching students with advanced STEM skills. Rather, BA has proven to be equally effective whether it is used to introduce non-science-literate students to basic concepts of environmental science and basic civic issues of environmental contamination or to provide advanced training in environmental site assessments and to model groundwater contamination to future environmental professionals.

For interested instructors, information about BA and a guided walkthrough of the simulation can be found at www.brownfieldaction.org. By contacting the lead author (Bower), one can obtain a username and password to access the simulation, see the library of documents, maps, and images related to the simulation and its use in the classroom, and visit the "User Homepages" where the authors from the collaborative network describe their use of BA in more detail than is done in this paper and provide additional documents and maps. These instructors have expanded the pedagogy of BA by utilizing the simulation in unique ways and in contributing new curriculum. In the "User Homepages," new or potential users can find an instructor whose use of BA parallels their own, begin a dialogue, and become part of the collaborative network.

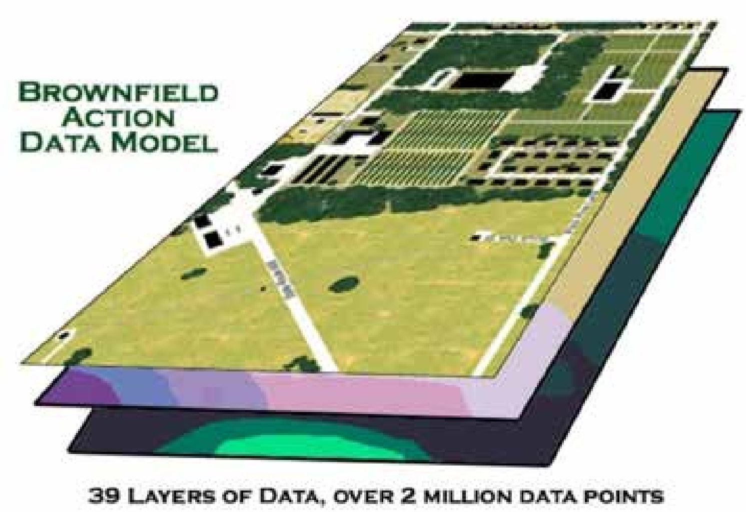

FIGURE 2. Data can be obtained for surface and bedrock topography, water table, water chemistry, soil characteristics, and vegetation as well as data from tools like soil gas, seismic reflection and refraction, metal detection and magnetometry, ground penetrating radar, and drilling.

Teaching High School Students the Fundamentals of Environmental Science

Joseph Liddicoat, *Barnard College*

Using the interactive, web-based Brownfield Action simulation, a total of 48 public high school students from the five boroughs of New York City who were enrolled in the Harlem Education Activities Fund (HEAF) were taught environmental science in a way that combines scientific expertise, constructivist education philosophy, and multimedia during 12-week programs in the fall of 2009, 2010, and 2011 at Barnard College. In the BA simulation, the students formed geotechnical consulting companies, conducted environmental site assessment investigations, and worked collaboratively with Barnard faculty, staff, and student mentors to solve a problem in environmental forensics. The BA simulation contains interdisciplinary scientific and social information that is integrated within a digital learning environment in ways that encouraged the students to construct their knowledge as they learned by doing. As such, the approach improved the depth and coherence of students' understanding of the course material.

In Barnard's partnership with HEAF, BA was used in modular form to gather physical evidence and historical background on a suspected contamination event (i.e., leakage of gasoline from an underground storage tank) that resulted in the contamination of the aquifer in a fictitious municipality, Moraine Township. The HEAF students assumed the role of environmental consulting firms with a fixed budget to accumulate evidence about a parcel of land intended for a commercial shopping mall and to report the feasibility of using the property for that purpose. Through the integration of maps, documents, videos, and an extensive network of scientific data, the students in teams of three and working with a Barnard undergraduate mentor engaged with a virtual town of residents, business owners, and local government officials as well as a suite of geophysical testing tools in the simulation. Like real-world environmental consultants, students had to develop and apply expertise from a wide range of fields, including environmental science and engineering as well as journalism, medicine, public health, law, civics, economics, and business management. The overall objective was for the students to gain an unprecedented appreciation of the complexity, ambiguity, and risk involved in investigating and remediating environmental problems.

The Barnard undergraduate mentors were familiar with BA from doing the simulation as part of an introductory science course. The mentoring included weekly assistance with writing and mathematical exercises, and guidance in writing a Phase I Environmental Site Assessment report that was required of each HEAF student. Assessment of the program included weekly journals reviewed by one of us (RK) at Columbia University's Center for New Media Teaching and Learning. The student mentors also provided information throughout the program on the progress of the students and their role in the program.

Overall, the students responded well to computer-based learning, especially the students who perceived themselves to be visual learners. Videos were especially effective in the instruction, as were hands-on laboratory activities (e.g., sieving of sand, permeability measurement exercise, measuring movement of a fictitious underground plume in a water model) as evidenced by open-ended journal responses from the students. One additional activity mentioned by nearly every participating student was the weekend retreat to Black Rock Forest, a 3,830-acre second-growth forest near West Point, NY, which Barnard helps to support. This retreat provided the HEAF students an opportunity to interact informally with each other and the HEAF staff, their mentors, and the Barnard instructors. Those two days allowed immersion in topics about geology, biology, botany, and ecology that the students did not encounter in the urban environment they lived in. As the 12-week program progressed, students frequently expressed their concern about gas stations in their neighborhood, which is a potential form of brownfield known to all of them. An indication of sustained interest in the program was the high percentage of student attendance, considering the students' sometimes difficult commute on public transportation from the five boroughs to Barnard within an hour of when they were dismissed from their high school. Average weekly attendance was 91% in year one, 98% in year two, and 92% in year three. Recommendations made by student mentors based on their experiences with the program include the suggestion that the mentors be utilized more fully in the instructional process to allow them to provide more context and other scaffolding support during group work time. This would allow for less large group lecturing and more peer instruction, as participants reported benefitting more from structured group time with mentor guidance than from the full group lecture components of the curriculum.

Briane Sorice Miccio, *Professional Children's School*

Brownfield Action has been used for four years in a high school Environmental Science class consisting of students in grades 10, 11, and 12. The class met 40 minutes each day, five days a week for seven weeks. During this time, the students investigated the gasoline plume emanating from the BTEX gas station and then wrote a Phase II ESA.

BA has been an invaluable tool in demonstrating many of the concepts covered in the curriculum. It has given the students a "hands-on" opportunity to put into practice the topics and skills they have learned. They were able to study a number of concepts, including groundwater movement (porosity, permeability, D'Arcy's Law), topography and contour mapping, and the chemical and physical properties of gasoline, while simultaneously experiencing how the knowledge of these concepts can be applied in a real-world situation. There was also an in-class demonstration of the movement of a contamination plume through a cross section of an aquifer, as well as a sediment size analysis using sieves to separate a sediment sample "taken" from the ground near the BTEX gas station. Students were able to physically see the different components of sediment and relate the different sized particles to the speed with which groundwater, and any inclusive contamination, is able to flow. With BA, students are able to learn, apply their knowledge in an ongoing interdisciplinary exercise, and see how all of these separate concepts taught in environmental science class tie together in the real world.

The Environmental Science course has been taught for seven years with BA being used for the past four years. BA made a tremendous difference, satisfying both the goals of the curriculum as well as enhancing student interest. Students are given the opportunity to investigate the environmental, social, and economic issues facing a community that is forced to deal with a brownfield and contamination of the local environment. New York City has over 40,000 brownfield sites, many of which are unknown to its residents. When students who live in the city work with BA, whose narrative deals with the ramifications of contamination in a small town, they are able to gain a better understanding of the magnified ramifications in a larger city. This, in turn, will make them socially aware of the effects of a brownfield on the people surrounding it.

Typically, students execute the "learn and apply process," where they learn in class and apply these concepts to a one-time lab exercise and exam before moving on to the next topic. However, with BA, the students are enthusiastic about applying what they have learned in a more interesting, realistic, and interactive format. Since the implementation of BA, students have been more receptive, and it has sparked more questions and comments than ever before. The students' questions have also demonstrated a deeper understanding of the subject matter than with traditional textbook work. The students are also able to incorporate problem-solving skills, exercise leadership skills and management strategies, and work collaboratively. Moreover, they are able to recognize the social and economic ramifications of pollution. In addition, BA's demonstration of the work of an environmental site investigator has, on more than one occasion, inspired students of mine to pursue the field of environmental science in college. Since my students are all college bound, the fact that Brownfield Action inspires interest in this field, particularly now when we need the next generation to be environmentally conscious, is gratifying and demonstrates the value of Brownfield Action within a high school curriculum.

Bess Greenbaum, *Columbia Grammar and Preparatory School*

Columbia Grammar & Prep is a private K-12 school in Manhattan, NY. The Brownfield Action simulation was utilized in two sections of the yearlong environmental science elective course, open to juniors and seniors. (One section had nine students; the other had 14. All of the 23 students were in either 11th or 12th grade, except for one in 10th grade). The high school students investigated the gasoline plume and associated drinking water well contamination portion of BA simulation. The goal of the project was to engage the students in some real methodologies used to detect and delineate contaminant plumes.

Students completed the investigation in teams of two or three over seven weeks. Groups were chosen by the instructor, who had, at this point, a fairly good sense of each student's ability and motivation level. In order to avoid the common pitfall of one student in the group doing all the work, students were grouped according to similar ability and motivation levels. This was a successful tactic. First, students were introduced to the concepts of brownfields and superfund sites. Then, they were shown how to log onto and navigate the BA computer simulation and the features for each new test. The students found the online interface to be very user-friendly.

Each team conducted tests and made maps of the gasoline plume, but each student was responsible for submitting their own final four- to six-page report along with four hard-copy maps. One map was a basic site map, and three were topographic maps of the site highlighting different data: surface topography, bedrock topography, and water table elevations. Students utilized two tests for contamination provided in the simulation: soil gas sampling and analysis and drill/push testing. Prior to conducting these tests, the instructor spent two or three class periods discussing with the students the major components and characteristics of gasoline. Students discovered that gasoline is a mixture of many substances, each with its own physical and chemical properties. We discussed that gasoline contained floating, volatile, and water soluble parts. For this investigation, we focused on two tests for the presence of gasoline provided in the simulation. First, the Soil Gas Sampling and Analysis (SGSA) tested for hexane, a volatile component found in the air pockets of the soil. The second test detected the presence or absence of benzene, a water-soluble component. Once the presence of hexane in the soil was confirmed, students used the Drilling and Direct Push test to see if there was any benzene in the groundwater. Students learned that the tests were performed in this order because it was financially practical; if gasoline had not been present in the soil, it would have likely been wasteful to perform the more expensive and time-consuming test on the groundwater. The final report submitted by each student had three main parts: (1) a summary letter to the EPA outlining reasons for, and results of, their investigation; (2) a description of investigation methods, testing procedures, and data; and (3) analysis and interpretation of the data.

Students varied widely in their spatial visualization abilities. Some were quite challenged by creating and understanding the meaning of the hand-drawn topographic maps. While tedious, this tactile and methodical process improved student understanding of mapping; however, comprehending the meaning of the aerial view of the plot of the hexane data (from soil gas measurements) and the cross-sectional view of the benzene data in the groundwater contaminant plume was not so obvious for some. The concept that each contamination map represented a different orientation (either cross-section or aerial view) of the contaminant plume was repeatedly emphasized. Students understood why there was a need to test for a volatile compound (hexane) in the soil and a soluble one (benzene) in the water table, but their understanding of sediment properties and the movement of groundwater was simplistic.

The BA simulation was a good classroom experience. Based on observations, students enjoyed the self-paced group work. Two adjustments for future use are suggested. First, introduce exercises in spatial orientation earlier on in the year. This would help students grasp the concept of topographic maps more easily, and they would be better equipped to identify and draw contour lines based on elevation points. Second, the experience could be enhanced with hands-on demonstrations of sediment size class and porosity/permeability of different sediments. These adjustments would likely allow students to take a more independent role in the investigation, and require less instructor guidance as they investigate the task at hand.

Although students were given a budget, the focus was on completing the Phase II investigation—regardless of cost. Some students were initially mindful of how much each test cost, but once they knew that it did not really matter how much they spent, they no longer paid attention to this feature of the simulation. Students did, however, take advantage of the Moraine township history and interviews with the citizens in order to make their final assessment and report. Another tactic that might improve student autonomy and the BA experience would be to have them work together to figure out the most logical order of steps to take in the investigation process. A class discussion of crime shows or *A Civil Action* would facilitate this. Once they reach consensus on a logical way to carry out the investigation, they could be introduced to the simulation's tools.

Teaching Environmental Science Students Fundamentals of Hydrology and Environmental Site Assessment

Bret Bennington, *Hofstra University*

Brownfield Action (BA) is used throughout the entire semester in both an undergraduate hydrology course (Hydrology 121) and a graduate hydrogeology course (Hydrogeology 674). These are combined lecture/laboratory courses taken by students pursuing degrees in geology, environmental science, or sustainability studies, most of whom are motived by an interest in applying science to solving environmental problems but who have little prior experience in groundwater science. Students are assigned to groups of three or four to form consulting teams. Teams are provided class time each week during laboratory to meet and coordinate online work performed individually outside of class hours. Students use the simulation to conduct a Phase I ESA (Environmental Site Assessment), and each group is required to make a presentation to the rest of the class detailing their findings and to submit a Phase I ESA report midway through the term. During the second half of the semester the teams work on a Phase II investigation. Final group presentations communicating the results of the Phase II investigation are made at the end of the term, and each student is required to submit an individual Phase II ESA report for evaluation. Students use critical feedback from the assessment of the Phase I materials to improve their Phase II presentation and reports.

A useful attribute of the BA simulation is that important hydrologic concepts introduced in lectures and labs can be incorporated into different stages of the online BA investigation, providing students the opportunity to practice applying these concepts in realistic, problem-solving activities. For example, in one laboratory exercise, students measure the porosity and hydraulic conductivity of a sediment sample obtained (hypothetically) from the abandoned Self-Lume factory site in the BA simulation. In another exercise, students learn how to calculate the direction and magnitude of a hydraulic gradient from hydraulic head data collected from monitoring wells. As part of their Phase I and Phase II investigations, students use these sedimentological measurements and groundwater analytical methods, in combination with data obtained in the online simulation, to calculate flow volume and seepage velocity beneath the Self-Lume site to assess potential impacts to the town water supply well. Students must also incorporate into their investigations knowledge of groundwater law and the regulations and standards governing environmental investigations, methods of aquifer testing and analysis, and the behavior of different forms of groundwater contaminants. To complete their ESA investigations within the BA simulation, students are thus required to integrate a wide range of data, methods, and concepts learned across the course.

Navigating the BA simulation also introduces students to the different components of civil government and the variety of agencies and departments involved in regulating and maintaining public health and groundwater quality. Students are drawn into the simulation by the authenticity of the online world provided, which is supported by realistic, richly detailed documents, newspaper articles, videos, and video and text interviews with public officials. It is a revelation to most students that so much useful information on potential environmental problems can be obtained just from interviews and municipal documents. In addition, the BA simulation provides many opportunities for students to develop critical thinking and problem-solving skills, as well as professional and technical skills, most importantly the ability to interpret, summarize, and effectively communicate technical information. As part of their course requirements, students must produce two formal, professionally written and formatted technical reports, and one informal and one formal oral presentation, and they must draft topographic, water table, and bedrock contour maps, as well as maps summarizing data from different aquifer tests and analyses. Finally, students gain valuable experience working cooperatively as part of a team focused on solving problems on time and within a reasonable budget. (Student teams are billed for all activities within the simulation and are assessed on how cost-effective their investigations are.)

In the past year and a half students were surveyed to determine their perceptions of the effectiveness of BA as a teaching tool. Student response to the BA simulation has been overwhelmingly positive, with a large majority of students indicating that BA was successful in facilitating student learning and providing experience with data analysis, interpretation, and problem solving (see Figure 3). More recently, in the fall of 2013, a SENCER Student Assessment of Learning Gains (SALG) instrument was deployed in the Hydrology 121 course at Hofstra University (nineteen undergraduate geology and environmental resources majors) to assess student gains in understanding and skills derived from their experiences with the semester environmental site assessment project built around the Brownfield Action simulation. Results from this assessment indicate moderate to large gains in understanding of course content (Figure 4) and relevant cognitive skills (Figure 5) learned and practiced while working with the BA simulation.

Many students report that BA increased their interest in pursuing hydrogeology and environmental consulting as a career (although some have also indicated that they learned from using BA that this was not the career path for them). Students have also reported that knowledge and experience of how to conduct Phase I and Phase II ESA investigations obtained through the BA simulation have been a very positive factor in interviews for jobs in environmental consulting. As one student wrote, "The Brownfield Action simulation not only helped me define a career goal, but it also helped me land a job in the environmental field. The skills and knowledge I gained through the simulation not only made my résumé look stronger to future employers but it allowed me to impress interviewers through conversation. Many potential employers were impressed by the fact that I knew enough about federal regulations and environmental concepts to even just carry on a discussion about Environmental Site Assessments."

The BA simulation has proven to be an effective teaching tool for three main reasons. It recreates the ambiguity of real-world problem solving by providing students with an open-ended set of environmental problems, and it requires that they apply what they have learned in the classroom without ever being told exactly what to do. It provides a richly detailed and realistic virtual world that students find interesting and that engages their curiosity by presenting them with realistic environmental problems to solve. Finally, the BA simulation provides a framework for demonstrating key concepts developed in hydrology/hydrogeology courses. Because much of the lecture instruction in these courses involves the mathematical analysis of groundwater flow, the students benefit from being able to apply concepts such as hydraulic conductivity, hydraulic gradient, hydraulic head, and seepage velocity to solve applied problems within the framework of the BA simulation. This helps the students to better understand these concepts, and it greatly increases their interest and engagement in hydrogeology. Students routinely comment on how much they enjoy working in the simulation and it has inspired a number of students to pursue careers in environmental consulting and groundwater remediation.

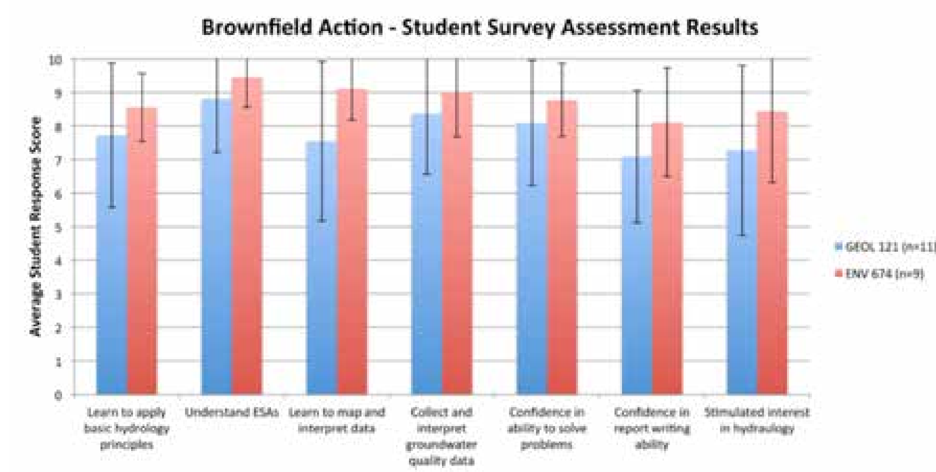

FIGURE 3. Average student responses to questions asking them to rate the effectiveness of the Brownfield Action simulation for aiding student learning. Responses ranged from 1 (most negative) to 10 (most positive). Error bars indicate average +/- one standard deviation.

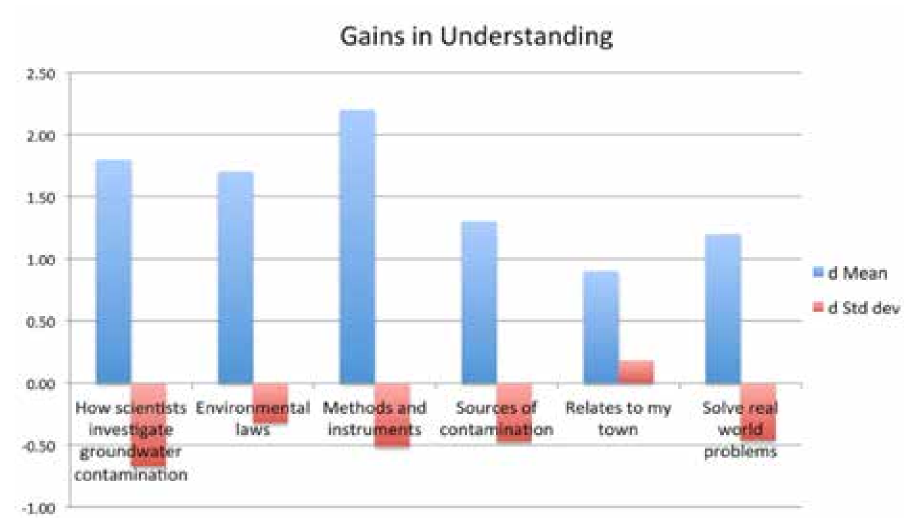

FIGURE 4. Changes from the beginning to the end of the semester in the mean (d Mean) and standard deviation (d Std dev) value of responses to questions asking students to rate their understanding of environmental and hydrologic concepts learned in the course working with the Brownfield Action simulation. An increase in the mean of the responses indicates a gain in understanding relative to a 5 point scale. A decrease in the standard deviation value indicates greater agreement among student responses.

Tamara Graham, *Haywood Community College*

Haywood Community College serves a predominantly rural community in the Appalachian Mountains roughly one-half hour west of Asheville, North Carolina. Haywood's Low Impact Development (LID) Program was launched in 2009 to provide workforce training and resources to foster more sustainable development in the region. Though

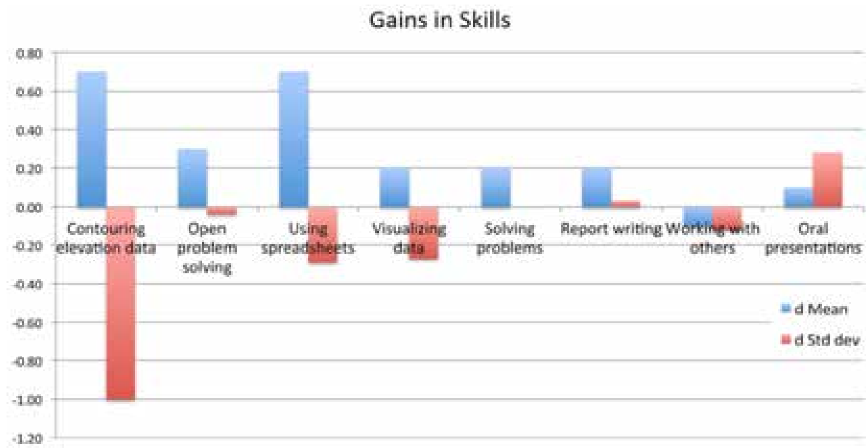

FIGURE 5. Changes from the beginning to the end of the semester in the mean (d Mean) and standard deviation (d Std dev) value of responses to questions asking students to rate their ability to apply academic skills learned or practiced in the course working with the Brownfield Action simulation. An increase in the mean of the responses indicates a gain in ability relative to a 5 point scale. A decrease in the standard deviation value indicates greater agreement among student responses.

the LID Program is relatively new, it is part of the College's highly regarded Natural Resources Management Department, which has offered two-year associate degrees and professional certificates in Forestry, Horticulture, and Fish and Wildlife for more than 40 years. The LID Program complements these established programs by offering students the opportunity to study innovative strategies for mitigating the impact of development on natural systems, particularly the hydrologic cycle.

LID 230, *The Remediation of Impacted Sites*, is a required course in the LID Program that surveys issues related to environmental contamination from the Industrial Revolution in the nineteenth century to contemporary 21st-century brownfields remediation programs:

> This course is designed to familiarize students with various scale remediation projects to enhance understanding of the role environmental repair has in sustainable development. Emphasis will be placed on case studies that cover soil and water remediation efforts necessitated by residential, commercial, industrial, governmental, and agricultural activity. Upon completion, students will be able to discuss and utilize the tools and technologies used in a variety of soil and water remediation projects. (Course description from *HCC Catalog & Handbook*)

From the perspective of LID, the remediation of brownfield sites offers communities perhaps the greatest return on investment in terms of sustainability. Brownfields are among the most contaminated sites environmentally, and their remediation spurs reinvestment in otherwise dilapidated urban areas, creating walkable, vibrant spaces for living and working where infrastructure already exists, rather than necessitating further encroachment of development on rural land or "greenfields."

In addition to a Brownfield Action (BA) training seminar held at Barnard College, the BA website contains a User Section with curriculum resources that have been have been an invaluable, engaging resource for developing Haywood's LID 230 course. In the spring semester of 2011 and 2012, BA resources were first introduced at approximately week five of the sixteen-week semester course, with a close reading of *A Civil Action*. The shared curricula and resources, such as reading guides made available in the BA User Section, provided students with compelling historical background on the origins of current brownfields programs. Building on this foundation, in the final third of the semester students worked in small teams with the simulation to develop a Phase I ESA Report and supporting topographic and inventory maps. The BA video interviews, narrative, and interactive simulation piqued student interest and facilitated understanding of the complex, interdisciplinary, even labyrinthine nature of environmental remediation. Site exploration afforded by the simulation allowed LID students to work at their own pace to cultivate attention to detail (careful detective work) while simultaneously being mindful of the bigger picture. Coupled with students' study of case studies of local remediation projects, the simulation effectively conveyed the complex and interrelated political, environmental, economic, and social factors at issue in environmentally contaminated sites and the necessity of collaboration among diverse entities to facilitate remediation and reuse.

Rather than appearing trite in the face of the somber topic, the playful nature of the simulation, with myriad puns and entertaining diversions woven through the narrative, helped to engage students and demystify the otherwise intimidating content. The fear of the effects of environmental contamination and intimidation regarding the process are perhaps the largest factors hindering collaborative public and private action to remediate sites. The BA simulation effectively addresses these barriers through its appealing, approachable format, effectively fostering collaboration among students to address complex problems and work toward solutions.

The BA simulation has provided an engaging learning opportunity for HCC's students. Several LID graduates have obtained employment with local and regional planning agencies, where their experience with the BA simulation has proven invaluable in addressing complex brownfields projects in their respective communities. HCC appreciates the opportunity to integrate this innovative simulation into our curriculum and is eager to assist Barnard College in expanding its access as an educational resource to further sustainable development goals in the region.

Douglas M. Thompson, *Connecticut College*

The Brownfield Action (BA) simulation has provided an important component of the course Environmental Studies/ Geophysics 210: Hydrology at Connecticut College since the fall of 2004. Attendance at a Brownfield Action seminar the previous year showed that the simulation was an ideal means to replace a paper-based simulation used previously. As an experienced user of BA, I can confirm that it is a wonderful learning tool that has brought a very realistic group activity to my classroom. The program also does a very good job helping students develop the scientific background and confidence needed to find employment in the groundwater consulting industry. More importantly, students enjoy the BA module and learn a great deal about basic project management and group collaboration skills that apply to a range of disciplines.

My first job after college was as a Project Geologist for a groundwater consulting company in New England. It was a good first job, but my undergraduate geology major and hydrology course had not prepared me for the types of decisions faced on the job. Years later as an instructor of a hydrology course, it was important that I share my consulting experiences in order to help prepare undergraduates for what can be a very good job opportunity after graduation. The BA simulation provides an excellent replication of many of the components of a Phase I site investigation. Several former students who now work in the groundwater consulting industry have said that they greatly appreciated the background they developed using the simulation.

In my class, students are divided into groups of two or three and are asked to investigate the contamination at the BTEX gasoline station. The students are required to determine whether contamination exists and to delineate the nature, extent, and source of contamination. Students are encouraged to use the soil gas sampling and analysis tool and to determine a rough map of where volatile organic compound concentrations are highest. The students are then required to install at least three shallow wells and one deep well to document the approximate source of the contamination and direction of flow in both the horizontal and vertical directions. Drilling location and well placement are important decisions for a successful project, and students often display a great deal of trepidation when they begin to install monitoring wells. The cost of a poorly placed well is an important reason for this. As someone who has stressed over drilling holes for real monitoring wells, I know that the angst that students display is a good indication that BA realistically simulates the decision-making atmosphere. The students then use the survey instruments, sample analysis options, and the resulting data to produce maps of the BTEX gasoline contamination plume and the free-product plume. Students complete a group report that presents their findings.

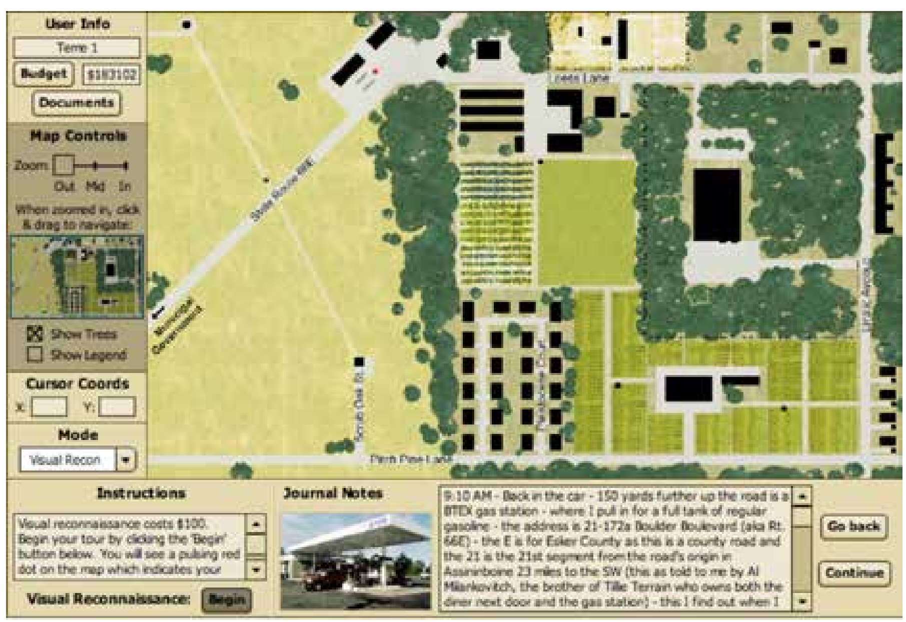

FIGURE 6. The Brownfield Action "playing field" in the reconnaissance mode visiting the BTEX gas station.

To supplement the basic materials supplied with the computer simulation, the program is augmented with additional data sources and activities. Existing documents as well as newly created documents are placed as a reserve in our library to replicate the task of going to government buildings to search municipal and state records. Each group is provided with a small sample of loess and asked to classify the soil based on a textural method. Students are taken on a field trip to the campus power station to see two large underground storage tanks. A mock site visit is also made there to identify potential sources of contamination and locations where monitoring wells might be installed. The BA simulation is also used as a means to demonstrate the basic principles of Darcy's Flow and hydraulic conductivity learned in the class. The students are asked to complete an estimate of the rate of groundwater movement based on some simulated pump test data created for this purpose and the groundwater table slope they determine from their BA wells.

BA provides an excellent opportunity for students to understand how the site assessment process is approached. The simulation adds a sense of realism to the sometimes abstract topics learned. BA has become a very important component of Environmental Studies/Geophysics 210: Hydrology, and the program will be used as long as its software is viable.

Training Undergraduate and Graduate Students in Advanced Courses in Hydrology and Environmental Remediation

Larry Lemke, *Wayne State University*

Brownfield Action was originally incorporated into GEL 5000—Geological Site Assessment—at Wayne State University during the Winter-2010 semester as part of an NSF CAREER grant that focused on groundwater contamination in previously glaciated urban areas. BA continues to play an integral role in this course, which is offered to both graduate students and upper division undergraduates and typically attracts 20 to 24 students each time it is offered. BA forms the basis for a term project in much the same way that it is employed at Barnard College: teams of students at Wayne State use the BA simulation as the basis for formulating Phase I and Phase II Environmental Site Assessments and reports.

In the first phase, students strictly follow ASTM Standard E 1527-13 (formerly E 1527-05). After completing site reconnaissance, records review, and interviews (no sampling is allowed except for Topographic Surveys), students document their findings, opinions, and conclusions following the ASTM specified report format. In the second phase, students choose two Recognized Environmental Conditions (RECs) to be investigated following ASTM Standard E 1903-11. The 2011 revision of this standard prescribes application of the scientific method to evaluate RECs. To begin this process, students must schedule an interview with their client (the course instructors) to recommend *Objectives*, *Questions* to be answered, *Hypotheses* to be tested, *Areas* to be investigated, a *Conceptual Model* for contaminant migration including target analytics, a proposed *Sampling Plan*, and an estimated *Budget*. During the interview, one course instructor plays the role of a naïve business manager focused on liability and budget issues, while the second course instructor plays the role of an environmental manager who asks probing technical questions. After receiving client authorization, student teams proceed to implement their sampling plan and complete the Phase II ESA. In our experience, the role play exercise adds another realistic dimension to the BA simulation by providing students practice in communicating technical information and recommendations to clients in an oral format (in addition to writing professional reports).

Most recently, Gianluca Sperone, a co-instructor in the WSU course, developed an effective innovation by utilizing ESRI ArcGIS tools to perform the Phase I ESA analysis. After converting available materials from the BA simulation into ArcGIS Geodatabase format, he mapped the information accessible to student investigators during the Phase I site visit and interview process. Subsequently, he used the ArcGIS Spatial Analyst Extension to model potential subsurface contaminant migration in the event of a release into the BA simulation environment. In this way, Sperone was able identify potential areas for Phase II ESA recommendations and demonstrate the utility of GIS tools to perform analyses and prepare professional materials for communicating project results.

Feedback from our students has indicated that the authentic, realistic nature of the BA simulation greatly enhanced their ability to understand and apply the relevant ASTM standards. One student wrote: "I thought the BA simulation was invaluable to students. The Phase I ESA knowledge gained from reading through the standard is reinforced with the game. It puts a practical twist on a document that can be difficult to focus on (hooray for legal jargon!). The experience will greatly aid students heading into consulting/government jobs."

Angelo Lampousis, *City University of New York*

The Brownfield Action simulation and curriculum has been used at two different colleges of the City University of New York (CUNY). In both cases BA was adopted at the undergraduate and graduate levels of the course "Phase II Environmental Site Assessments" (City College of New York EAS 31402 [undergraduate] and EAS B9235 [graduate], Hunter College GEOG 383 [undergraduate] and GEOG 705 [graduate]). The combined number of students introduced to the BA simulation to date is 24. The academic background of the students involved ranged from geology, environmental sciences, and geography, to urban planning and sustainability.

The BA simulation was used as a refresher for the Phase I process, since most students had already completed the Phase I environmental site assessment course that is also a prerequisite for the Phase II course. The BA simulation served this purpose exceptionally well. Students had the opportunity to experience and practice a realistic interview component of writing Phase I reports as they interacted with the characters of the simulation. This addressed a specific gap in the CUNY curriculum that, while strong in using real data on real estate properties located in New York City (Lampousis 2012), treated interviews as a data gap (i.e., per ASTM designation E1527 – 05) due to legal and other restrictions on allowing college students to interact with property owners in an unsupervised manner. The BA simulation addresses this gap through its incorporation of a wide range of very thoughtful fictional interviews. The BA simulation experience for CUNY students was realized through several homework assignments culminating in a Phase I report. Due to time constraints, considerable amounts of information from the simulation, including data for topography, depth to bedrock, and depth to water table, were made available to CUNY students from the very beginning. Students were also assisted by the instructor in their construction of a conceptual site model.

Overall, the adoption of the BA simulation within the two CUNY colleges greatly reinforced student learning on the topic of environmental site assessments. The BA simulation provided an opportunity to test the knowledge and level of students' understanding achieved up to that point. Students were able to get a panoramic view of the process, from signing the initial contract to submitting a final report. Because everything they did in the simulation cost them money, they also experienced working within a budget. The BA simulation will be used in the future starting in the Phase I course offered in the fall, and there are plans to adapt the BA simulation for a geographic information systems platform in the "Introduction to GIS" scheduled for the spring semester 2014. The latter will be in collaboration with Gianluca Sperone of Wayne State University.

Saugata Datta, *Kansas State University*

Brownfield Action has been used at Kansas State University (KSU) since 2009 for the undergraduate and graduate students in the lecture and laboratory courses of Hydrogeology (GEOL 611, with an average of 20 students mainly from the geology, biology, agricultural and civil engineering departments), Introduction to Geochemistry (GEOL 605/705, 10 students, mainly from the geology, agronomy, and chemistry departments), and Water Resources Geochemistry (GEOL 711, eight students from veterinary medicine, geology, and agronomy). All three have been offered as interdisciplinary courses.

In Hydrogeology, BA is utilized as the foundation for a one-month practicum. Students work in teams of three and are given complete access to the BA simulation and website including all data and documents. Student teams must choose a topic or specific problem to be solved within the BA simulation. Topics range from using the BA simulation and database for a Phase I ESA of the Self-Lume property or the BTEX Gas Station, for flow net exercises to delineate various contaminant plumes (gasoline or tritium), for simple permeameter measurements to understand hydraulic conductivity, or for utilizing the many soil exploration tools (drilling, seismic reflection and refraction, ground penetrating radar, soil gas) to determine plume location and its migration paths, and chemical characteristics of different contaminants. Lectures are developed based on the topics chosen. Each team is required to write a report on their findings and evaluate what they have learned from their practical experience with the simulation. Poster sessions have often been assigned so that students may share their experiences using the BA simulation with other students to demonstrate how different methods and principles are used to solve complex hydrological problems. Additional faculty members are invited to these poster presentations and interact with and question the student teams.

In Geochemistry, BA is used for one month as a case study as part of the final project. Students use BA in order to understand the chemical characteristics of organic contaminants, the chemistry of groundwater, and the use of various field or laboratory geochemical analytical tools to measure various contaminants, map these contaminants in the surficial soil cover, and create hydrochemical maps with piper diagrams for various inorganic contaminants. Students learn how different plumes will mix or impact each other. BA allows students to develop a clear understanding of the composition of different contaminants and their MCLs in the environment.

In Water Resources Geochemistry, BA has been used in collaboration with other users of BA from Lafayette College (LC) and Wayne State University (WSU). Students are assigned to investigate BA in order to write Phase I and II ESA reports. There are invited lectures from within KSU as well as video lectures transmitted by instructors from LC and WSU. Students from KSU present their findings to students in an Environmental Engineering course at LC and a geology course at WSU, who in turn present their findings to the KSU students. Working with instructors from WSU, students at KSU learn how to use ARC GIS on the BA database. The topics in this video conferenced course evolved from the joint use of MODFLOW and Groundwater Modeling Systems (EMS-i) in tracing groundwater contaminants in the BA aquifer.

Typical student comments about the use of BA include: "One of the greatest ways to connect to a real world problem and it was interesting how we were acting as consultants, and tried not to leak ideas to the other groups," and, "I learnt more about the application of Darcy's law when I was taught with BA, even the water table characteristics, and the direction of groundwater flow were more clear when BA was demonstrated to us." Students also commented on how they learned to work as a consultant and that one cannot make mistakes that might result in losing the contract or not making a profit. Several students have gone to job interviews and used BA to demonstrate their knowledge of ESAs and to respond to questions from the interviewers. BA played a significant role in the hiring of these students by government agencies and has also led to a dialogue with these agencies on how to use BA within communities they serve that are affected by brownfields.

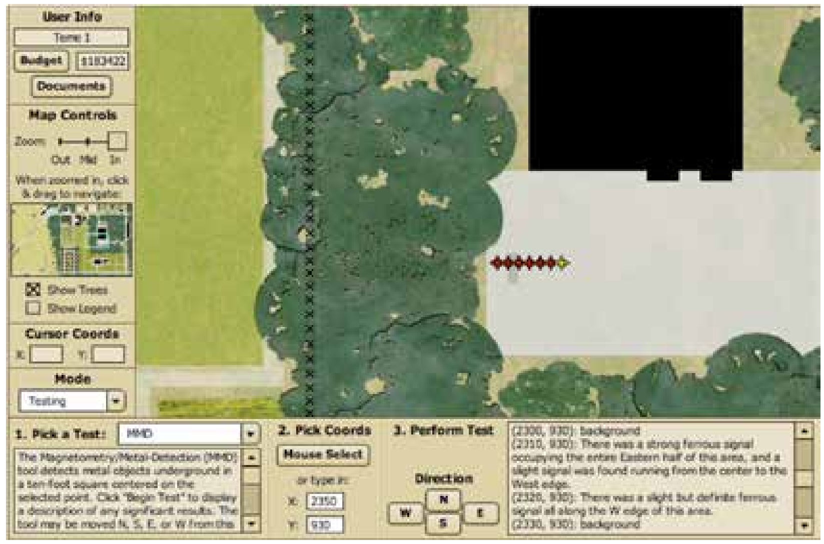

FIGURE 7. The Brownfield Action "playing field" in Testing Mode with zoom function applied and magnetometry/metal detection measurements being made.

Arthur D. Kney, *Lafayette College*

Over the last seven years the Civil and Environmental Engineering (CE) program at Lafayette College has used Brownfield Action successfully in two courses: Environmental Engineering and Science (CE 321) and Environmental Site Assessment (CE 422). CE 321 is an introductory course, and BA is used to introduce the issues of brownfields, remediation, and environmental regulations. CE 422 is a course in which students learn how to do Phase I Environmental Site Assessments (ESAs) consistent with ASTM 1527. Because most of the fundamental science needed to understand and participate in the BA scenario is taught to CE students throughout their first few years of our CE program, use of BA in CE 321 and 422 is targeted at applying their accumulated fundamental skills and knowledge in a realistic simulation in addition to teaching the details of the ESA process. Following a two-week exercise utilizing BA, students are prepared to do a real-time site assessment on neighboring properties.

My experience has shown that BA is very applicable to the field of civil engineering from initial investigation through remediation and that the interdisciplinary, realistic nature of BA provides an effective tool with which to teach aspiring civil and environmental engineers. Connections to the practice of civil engineering are played out in numerous scenarios in BA. For example, understanding how chemicals move through the water and soil is made evident through models that civil engineers are taught in water quality and water resource classes. Methods and practices used in remediation are common themes taught in upper level environmental engineering courses. Additionally, ESAs must be accomplished by an "Environmental Professional" as outlined in the US CFR 40:312.21. BA provides a wonderful storyline linked to believable data that ties together individuals and their community with industry and very real economic and environmental concerns. In order to piece together the truth, critical thinking skills must be used to interpret and communicate the significance of data obtained from the simulation.

In CE 422 especially, the incorporation of BA has tremendously improved student understanding of the ESA process as compared to classes taught prior to use of BA. Anecdotal evidence from student conversations, faculty observations, student test scores, and the fact that BA continues to be a central part of CE 422 all support this statement. Beyond CE 321 and 422, students have reported that BA has strengthened their ESA skills in senior-level design projects and has provided evidence of competence when applying for jobs. In fact, it is not uncommon to hear that students have not only gotten jobs because of their ESA skills but have also gone on to perform ESAs in their jobs. Because of these reports from students, future plans include introducing some form of an ESA course for engineering professionals. Incorporating BA would be integral, because of the fact that one can quickly comprehend the overall ESA process through the interactive, informative framework of the simulation.

As part of the collaborative network, Saugata Datta from Kansas State University (see above) and I have used BA to complement several courses. Our most recent course development is a team-taught course module between Kansas State and Lafayette. Graduate and undergraduates from both institutions have worked together reconstructing plume flow via groundwater models like MODFLOW and Groundwater Modeling System (EMS-i), using data from the BA simulation. Students connect the groundwater solution to the models in the existing BA simulation and make the BA narrative come alive as they learn how the various chemical and kinetics principles of contaminants behave throughout the BA storyline. In addition, other collaborative engagements have blossomed through BA team interactions, such as a recent set of academic video discussions between Wayne State University, Kansas State University, and Lafayette College students and faculty revolving around the overuse of key nutrients, phosphorous and nitrogen. Consistent with professional practice, future plans include developing a workshop open to environmental professionals interested in learning how to conduct ESAs. BA would be used to help professionals connect to the task at hand just as it has been used in CE 422.

Discussion

Assessing the Effectiveness of the Brownfield Action Simulation

All faculty using BA in their courses report high levels of student engagement with the simulation and increased confidence in students' ability to understand and apply science to solve problems. Although a simulation, BA is grounded in civil, legal, and scientific reality such that experience gained through BA is directly applicable to the real world. This is demonstrated by the many students who report that BA has assisted them in gaining employment as environmental professionals. Other important professional and conceptual skills reported being taught and learned in the context of the BA simulation include data visualization, map-making, budgeting, formal report writing, making formal oral presentations, as well as decision-making, dealing with ambiguity, teamwork, and networking in information gathering.

Reliable summative assessment of the pedagogical effectiveness of the BA simulation has not yet been performed due to the lack of appropriate control groups (the courses discussed above are not taught in multiple sections with some instructors using BA and some not) and a lack of appropriate data on student performance prior to the adoption of BA in courses. However, a variety of formative assessments of the BA simulation were incorporated throughout the design and initial use of BA at Barnard College to provide feedback and confirmation of the effectiveness of the simulation (Bower et al. 2011). We are currently developing and testing a survey-based formative assessment utilizing the SENCER SALG tool available online (http://www.sencer.net/assessment/sencersalg.cfm). A SENCER SALG instrument consists of a pre- and post-course survey taken online that provides instructors with useful, formative feedback for improving their teaching. A SALG instrument provides a snapshot of student skills and attitudes at the start and end of courses, allowing instructors to gauge the effectiveness of teaching strategies, methods, and activities such as the BA simulation (Seymour et al. 2000). A preliminary version of a SALG instrument designed to measure student learning gains resulting from working with the BA simulation has recently been deployed by Bret Bennington and analysis of the results show marked gains from the beginning to the end of the semester (see discussion above). At the next meeting of BA users in the spring of 2014 we will finalize this SALG instrument and begin deploying versions of it to measure the impact of BA on student learning in a variety of educational settings and applications.

Ongoing Work and Future Directions

The tenth in a series of seminars and training sessions for Brownfield Action will be held at Barnard College in April of 2014. Most of the early seminars were devoted to training new users of the simulation and to troubleshooting problems existing users were having. As the simulation evolved, two new versions of BA were produced making the simulation web-based, enhancing the features of the "playing field," and developing a "modularized" version that is more adaptable to creative new uses. While new users are still being trained, the ninth seminar held in the spring of 2013 was devoted primarily to the sharing of experiences teaching with BA and presenting new applications of BA developed by current users. These included using the data in the BA simulation to teach modeling and analysis using GIS, using the simulation to teach undergraduates about Phase I Environmental Site Assessments incorporating GIS, the use of the gasoline contaminant plume in the simulation as the basis for a six-week unit on toxins and environmental site investigations for high school students, the creation of evaluation tools for the assessment of the effectiveness of BA in an undergraduate hydrogeology course, the modeling of groundwater contaminant plumes from the BA database as part of graduate level student exercises, and discussion of new possibilities for furthering the BA simulation using 3-D gaming technologies.

It is apparent from the above reports that users continue to develop new ways of using BA to teach science in the context of civic engagement. While BA was not developed to teach GIS, the work done in this area suggests that the BA simulation can be easily adapted to enhance GIS instruction. The data- and context-rich virtual world of BA provides an ideal tool for realizing SENCER goals for teaching science through important civic issues and motivating students to learn and understand basic science. Environmental contamination and brownfields are universal problems in today's world and incorporate civic issues to which every student can relate. BA provides a virtual world and narrative in which students figure out for themselves how to apply basic scientific concepts learned in a course to solve real, practical problems. There is significant potential for further growth of the community of BA users but it is also apparent that BA must undergo significant technological change to bring it up to date with new advances in online delivery and learning technology. A "next-generation" Brownfield Action project is in the early stages of development in order to create a more interactive, 3-D game-based learning environment for the simulation. We would also like to add new data to the simulation, expanding the range of environmental toxins represented to include dense non-aqueous phase liquids (DNAPLS) and nitrates, two major sources of groundwater contamination. Developing the next generation of BA will require funding, and appropriate documentation of learning gains will be needed to make a case for continued investment in BA. To this end we are currently developing standardized student assessment tools using the SENCER SALG that will be deployed across the community of BA adopters. But most importantly, improvement of the Brownfield Action simulation will be facilitated through expansion of the community of instructors who use BA in their courses and who will continue to develop innovative approaches that can be shared across the BA collaborative network.

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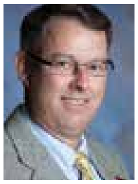

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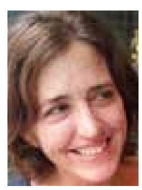

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