RESEARCH ARTICLE

Brownfield Action

An Inquiry-based Multimedia Simulation for Teaching and Learning Environmental Science

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Introduction

According to the EPA there are presently over half a million brownfields in the United States, but this number only includes sites for which an Environmental Site Assessment has been conducted. The actual number of brownfields is certainly into the millions and constitutes one of the major environmental issues confronting all communities today. Brownfield Action (BA) is an award-winning, web-based simulation and curricular model developed and used for the last ten years by Peter Bower, a senior lecturer at Barnard College, in his introductory environmental science course, to teach undergraduate non-science majors about brownfields, toxification of the environment, and civic engagement. (See Figure 1.) The BA multimedia environment was constructed in conjunction with the Columbia University Center for New Media Teaching and Learning (CCNMTL). BA is currently in use at nine additional colleges, universities, and high schools. Successful widespread, collaborative use of BA was made possible by development of modularized software, a robust server and website for outreach and peer support, as well as faculty training seminars. The testimony of instructors using the BA simulation in their courses, as well as an independent professional evaluation using largely formative methods have validated that BA produces a significant increase in student understanding and learning across a wide spectrum of uses. The focus of this article will be on its use at Barnard College (BC).

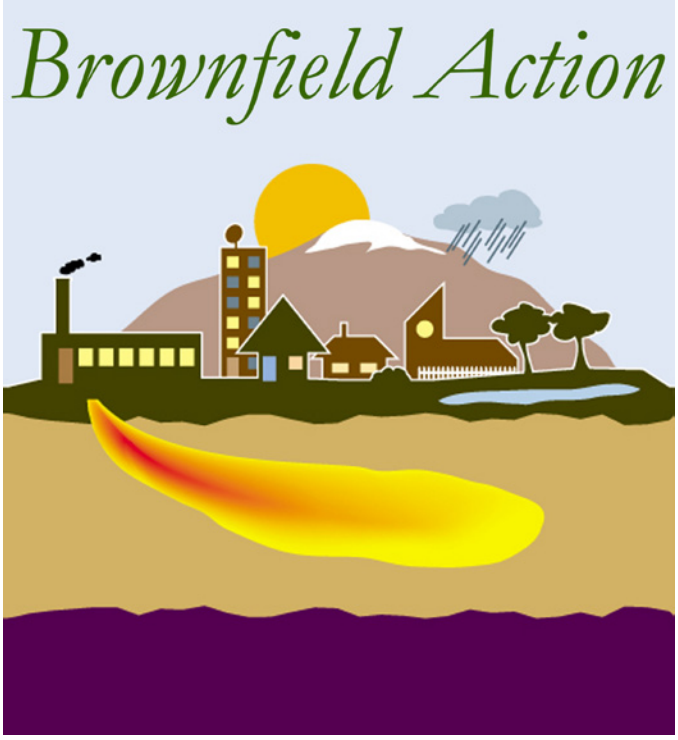

FIGURE 1. The Brownfield Action Logo

At the heart of BA is a web-based interactive learning simulation in which students explore and solve problems in environmental forensics. The playing field contains over two million data points in a three-dimensional grid whose playing surface is 2000 × 3200 feet (~150 acres) in a fictional town known as Moraine. Grid points hold many different types of natural data, including surface topography, depth to water table and to bedrock, soil or sediment type, and vegetation. The simulation's graphical user interface (GUI) allows students to utilize a host of tools, including: seismic reflection and refraction, ground-penetrating radar, magnetometry and metal detection, soil gas, and well and ground water sampling using drilling and push techniques. The GUI also includes numerous details about the fictitious town of Moraine: infrastructure (buildings, roads, wells, water towers, homes, businesses, and underground pipes and tanks), a municipal government complex with relevant historical documents and permits, and a town history and storyline that includes residents who may be "interviewed" by students (see Figure 2).

The story that unfolds in the simulation is one of groundwater contamination in Moraine and the resulting underground contaminant plumes. As students become familiar with the simulated town and the history of the abandoned plant owned by Self-Lume, students gradually reconstruct the details of an all-too-familiar narrative. The Self-Lume factory, which until recently manufactured radioluminescent signs, has been badly mismanaged and employees have dumped radioactive materials into a septic field. A gas station is also discovered

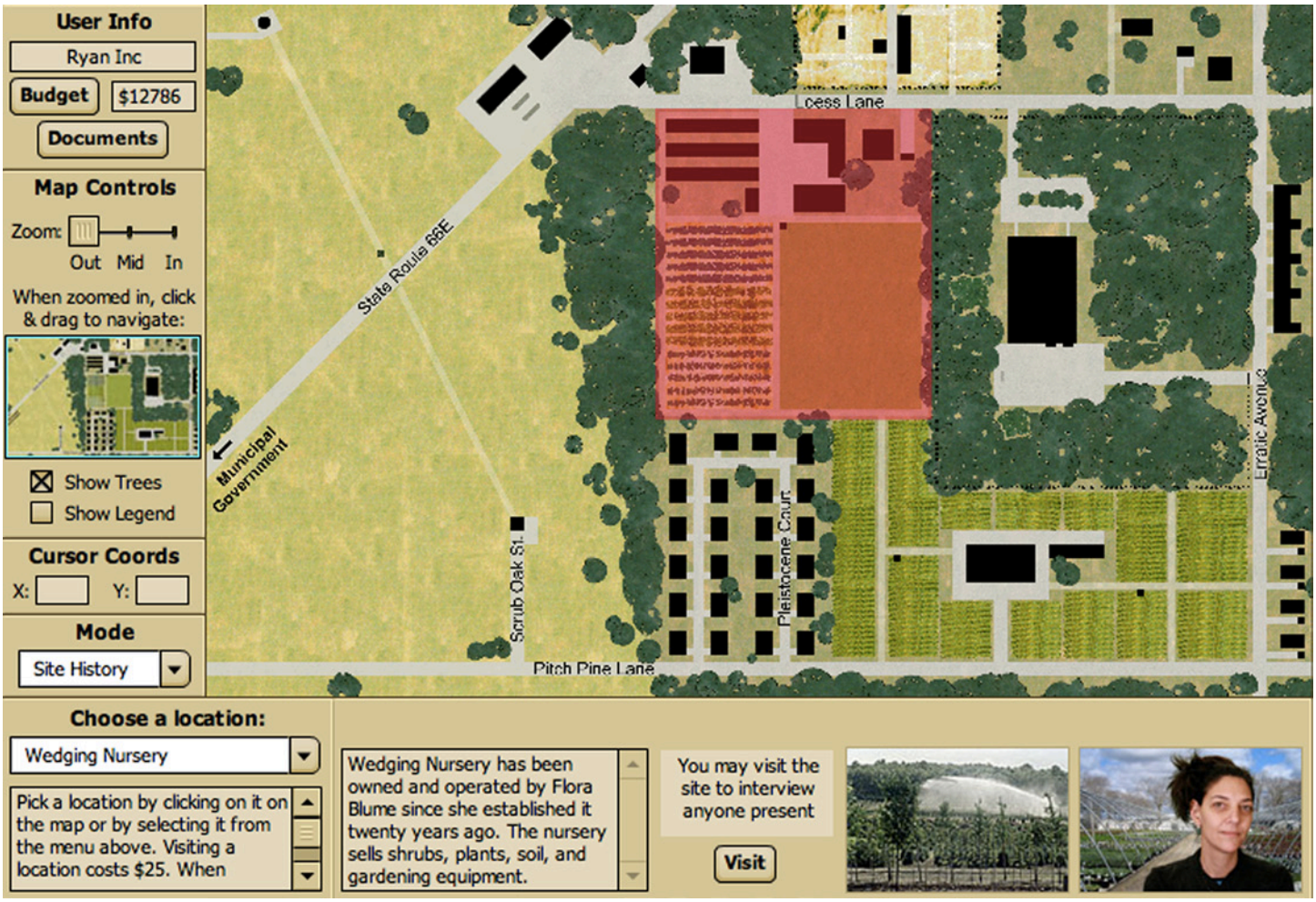

FIGURE 2. The BA site map is shown here with the History tab activated and with a student visiting the Wedging Nursery (highlighted in red). Photos of the nursery as well as the owner of the nursery (one of the characters in the BA story) appear and a video may be activated in which the owner answers a series of questions. Students may ask further questions (again at a price) by activating the interactive question mode. See the Supplemental Documents section for more screenshots of the BA simulation.

to have a leaking underground storage tank. Both have contaminated the local aquifer. Malls-R-Us wants to build a shopping center on the factory site. It is the job of the students to act as environmental assessors to determine if the site is safe.

The Simulation at BC

BA is a collaborative exercise that forms the foundation for twelve laboratory sessions. Pairs of students form environmental consulting companies, which are part of a storyline already in progress that each student must "buy into." Each company begins its investigation by viewing a simulated cable access program depicting an interview with the Malls-R-Us developer who describes plans to convert the abandoned Self-Lume factory site into a shopping mall (Figure 3). The teams then sign a contract with the developer, for whom they must perform a Phase I Environmental Site Assessment (ESA) of the abandoned factory and prepare a report for the developer on the advisability of proceeding with construction of the mall. The contract summarizes in detail the obligations as well as the goals for the semester-long investigation and provides a budget. Everything from the initial visual reconnaissance to the hiring of subcontractor firms to perform specific tests, costs the student company money, drawing from the budget provided in the contract. The simulation and supporting materials draw the students into active involvement, enmeshed in a "real," integrated world with a mystery to be solved. Each company must learn to obtain the maximum amount of information at the lowest cost, information that will help them make more important (and expensive) decisions later in the semester in order to fulfill their contractual obligations. Student companies compete to maximize profit while producing a report that accurately reflects reality.

Students obtain documents and historical and anecdotal information by visiting the municipal complex or interviewing individuals within the simulation (see Figure 4).

Students must pass tests and become "licensed" before utilizing any of the various forensic tools (see Figure 5). While students companies may begin drilling at any time, they quickly learn that this is a very expensive procedure not to be attempted in a blind search for contamination.

While BA is a collaborative project at BC, each student produces her own Phase I ESA report due seven weeks into the term using the information acquired by the team. After the Phase I ESA and the discovery that the municipal well has been contaminated, all of the student companies are hired by the EPA and work together for three weeks on a Phase II Environmental Site Investigation with each student preparing a Phase II report detailing the sources, nature, and extent of the contamination. Student companies also work as detectives to build character and story maps in order to understand the specific roles of individuals at the abandoned factory site. They assist prosecutors from the Department of Justice with forensic evidence and help build both civil and criminal lawsuits against

FIGURE 3 Seymour Buckmeister, president of Malls-R-Us, is interviewed by Frank O'Ryan on Esker County Cable News Access and describes his plans to convert the abandoned Self-Lume factory in Moraine into a high-tech mini-mall.

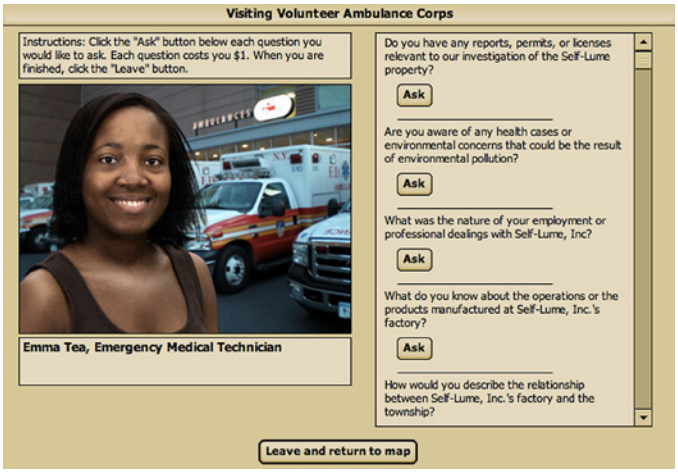

FIGURE 4 The GUI showing an interview with a member of the Moraine Volunteer Ambulance Corps. Here a student can visit each of the town's locations, developing anecdotal records by interviewing local townspeople and requesting and viewing documents.

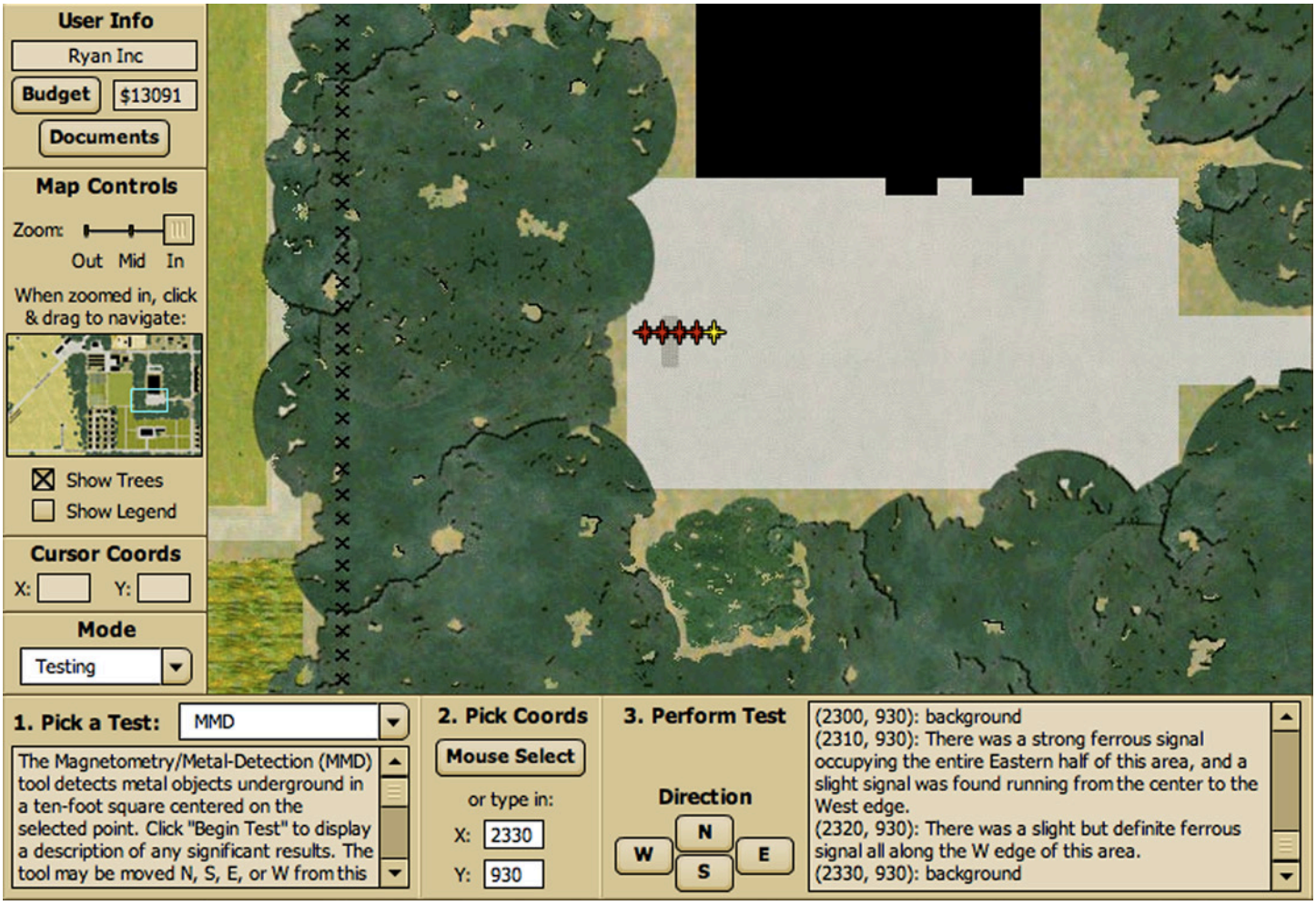

FIGURE 5. The GUI showing the use of the magnetometry and metal detection tool at the Self-Lume site. Here eight test options (such as ground penetrating radar, soil gas, metal detection and magnetometry, push and drill technologies, seismic profiling, etc.) are available, each with links to online reference material, a certification quiz, a practice option, and a "do test" option that incurs costs.

the responsible parties. In the final two weeks each student prepares a Phase III report detailing measures for remediation.

Lectures and one-on-one contact in the laboratory provide strategic thinking tools for planning a cost-effective investigation that evolves over time as the reality of the actual site emerges from ambiguity. Lectures also provide the information that students need to perform the Phase I, II, and III ESAs. This includes an interdisciplinary array of subjects, including: basic civics and the role municipal government, land-use and zoning, the laws governing the flow of groundwater and contaminant plumes, soils and sediments, drinking water standards, radionuclides, organic chemistry, environmental law, the economics of real estate, brownfields, toxicology, and topographic maps. The main objective of this integrated approach is to create a curriculum that provides students with an inquiry-based, interdisciplinary, and realistic construction of knowledge, one that contains ambiguity but also one that forces students to make choices based upon their perceptions of the interlocking realms of knowledge, theory, and, especially, direct observation and experience, and then to react and adapt to the consequences of their choices. In so doing, students are given multiple opportunities to tackle the complexity of a large-scale interdisciplinary problem and achieve an understanding of the interdisciplinary nature of the scientific process and its complicated relationship with economic, social, and political structures.

Students Use of BA

BA has been used for ten years as the foundation for one semester of the year-long Introduction to Environmental Science (IES) course taught at BC. The course has two 1¼ hour

lectures and one three-hour laboratory per week; there are eight laboratory sections of fourteen students each. These 112 students reflect the composition of Barnard as a whole: the 2,261 female undergraduates come from forty-seven states and more than twenty-seven countries; 12 percent are African-American, Latina, or Native American; 24 percent are Asian. Students are roughly evenly divided between first-, second-, third-, and fourth-year students. Approximately 8 percent of the students who take IES with BA become environmental science majors and move directly into upper level science courses; approximately 16 percent of these students major in another science; 76 percent of the students are, therefore, non–science majors taking this course to fulfill their science requirement. For most, it is their last academic contact with science. The development and implementation of BA at an independent women's liberal arts college was inspired in part to challenge the scientific interest and skills of female undergraduates, a demographic group that is historically underrepresented in the natural sciences.

STEM Education

Data from Barnard College show that 10 percent of the non–science undergraduates who take BA go on to take more advanced STEM courses, especially in environmental science but also in all the sciences. The question of whether BA impacts the decision to take advanced STEM courses has not been specifically studied, but anecdotal evidence, including unsolicited student comments, suggests that 1–2 percent of the BA cohort who never considered taking any more science do so as a result of their BA experience.

Assessment

A range of qualitative formative evaluation strategies have been employed using a modified model of Design Research (Bereiter 2002; Collins 1992; Edelson 2002). As with any design study, the aim has been to iteratively improve the intervention rather than trying to prove its efficacy through attempting to control the innumerable variables at play in this course; in this case, the course design, teaching strategies, technology, as well as the use of the technology have been reviewed and iterated many times. Evaluation techniques have included classroom observations, surveys, independent assignment analysis, and structured interviews. All assessment activities to date have been focused on student learning, especially on student learning with today's technology. Whenever possible, student perspectives have been incorporated into the evaluation design.

A comprehensive report on the design process of BA and the evaluation techniques used from 1999–2003 can be found in Kelsey (2003). This study chronicles the discovery, design, development, implementation, and evaluation of BA over a four-year period from prototype to full-fledged semester-long lecture and lab experience. Multiple formative assessment techniques were designed and implemented culminating in a qualitative ethnographic approach of monthly interviews of eight student volunteers to determine the impact of BA on the evolution of each student's learning process and attitude towards science through the duration of the course. 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, that BA improved student retention, and that students made linkages in their reports not likely to be made in a traditional teaching framework. It was 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, learned more content and in greater depth. This study also showed that BA supports the growth of each student's relationship to environmental issues and promoted transfer into the student's real-life decision-making and approach to careers, life goals, and science.

In 2003, BA was selected as a Science Education for New Civic Engagements and Responsibilities (SENCER) model curriculum. This award recognized the contributions BA has made to both teaching and inquiry-based learning as well as to the application of digital technology in the classroom. The award also recognized that BA encouraged civic-engagement by integrating this learning tool with the environmental, economic, and civic importance of brownfields and the toxification of the environment.

After the SENCER award, several grants that supported the development of BA also allowed project evaluators to gather assessment data using various methods with different groups of students over the years. Some of these include:

Critical Incident Reports

Critical incident reports, in which students wrote journal responses where they articulated a moment when they felt the

simulation was useful and described (1) what they were trying to accomplish or understand, (2) how using the simulation helped and (3) what would have been different if they had been using more conventional instructional materials, found that all students in the group studied (n=28) who were specifically interested in science liked the simulation. Three quarters of the non–science Barnard students also reported using the simulation as an overall positive experience, suggesting that it made science accessible. The responses indicated that the affordances of BA (as perceived by the students) fall into three categories: BA is an important *visual aid* (twenty responses), helping them to visualize issues such as the spread of groundwater contamination; the *narrative* elements of BA help them understand the complex forces involved in understanding real life environmental problems (twenty-five responses); and, *interactivity* as a primary value of the simulation in their learning, noting the authenticity of doing everything, from interviewing residents, to reading news accounts, to making cost analyses of using the various technical tools, all to produce a real-life ESA (twenty-five responses); in addition, some separately noted that the authenticity made it fun as well (five responses). Visualization, the narrative element and interactivity are all important components of authenticity. Rosenbaum (2007) emphasized the importance of authenticity for simulations that provide real-life interactivity for problem-solving so that students learn to "work with incomplete information, adapt to changing conditions, manage complexity, and fluidly create and share knowledge." While BA does not use augmented reality on location with students as in the Rosenbaum study, there is some evidence from this survey that some authenticity goals can been achieved within the laboratory setting using simulations like BA.

Student Surveys

Examination of a student opinion survey of sixteen statements rated by forty students (the majority were Barnard non-science undergraduates) about the use of simulations in the classroom on a six-point scale revealed that the majority of students agreed that BA's complex narrative helped them see the multidisciplinary nature of the BA model from different perspectives. Most agreed the decisionmaking aspect was an enrichment of their learning experience. Some still preferred learning course content using traditional classroom materials, but most found the interactive element, the ability to explore by trying things out and having the opportunity to take individualized pathways through the material, useful. Many agreed that the simulation was helpful because they could explore and make mistakes without real consequences and that the narrative helped them imagine what this kind of decisionmaking might be like in real life. Students were unanimous in their rejection of the idea that educational simulations increase social isolation by having students interact with virtual rather than real people.

Student Reports

Finally, content analysis of the final ESA reports produced by a Barnard cohort (n=25) were compared to the grades they obtained for the class and the ways in which they discussed the use of the simulation in their learning. The portion of the ESA that was analyzed using a validated four-level coding scheme asked students to provide a scientific basis to support their hypothesis about the alleged contamination of groundwater, including a description of water table characteristics, direction of groundwater flow, sediment analysis, D'Arcy's Law, and other evidence from the site. Results showed a correlation between how students felt about using the simulation and the quality of their site reports; a weaker correlation also existed with their final grades.

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There are, of course, limitations in the evaluation studies to date that will be addressed through further work. The conclusions brought forth in the most recent formative evaluation provide sound evidence for BA as an effective learning tool. However, some student resistance to nontraditional curricula in science courses that challenge them to learn a new way of learning (i.e. process and method over facts) continues to impact our results, especially when looking at student perceptions of learning. The BA team directly addresses this resistance in its faculty training sessions, suggesting strategies to help instructors be explicit and reflective with students about BA's approach. Also important to note is that even high-quality experienced faculty members must make multiple attempts to optimize the amount of guidance to use with BA for their particular audience. To that end, further evaluation with a larger sample size and increased data collection as more schools make use of the curriculum, and adjustments of evaluation instruments for more incisive findings, will likely lead to more conclusive positive learning outcomes.

Discussion

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: increased engagement; adaptations for students with high or low prior knowledge; effective replacement for expensive/impractical field trips; control over the pace and direction of learning; increase in student participation over large lecture hall formats; effectiveness in representing complex subject matter; application to realistic situations; and packaging of complex ideas into a consistent narrative. Much of the literature on computer-based simulations cited below is built upon the legacy of researchers such as Greenblat (1981), Lederman (1984), and Petranek (1992, 1994), who showed how paper-based educational simulations could motivate learners to be active participants in their own learning through individualized activities and immediate feedback. Many researchers are actively engaged in the study of particular teaching and learning strategies that employ a custom-created computer-based simulation or game similar to BA (Barab 2000, 2002, 2005; Dede and Ketlehut 2003; Rosenbaum et al. 2007; Kim et al. 2009; Jacobsen et al. 2009). And a number of researchers have explored the use of simulation technologies in creating virtual field trips as a response to educational, logistical and economic constraints (Arrowsmith et al. 2005; Whitelock and Jelfs 2005; Ramasundaram et al. 2005). Mayer and Chandler (2001) found that students who had more control over the pace and direction of educational simulations showed better learning outcomes than those who had less, or what Betrancourt (2005) has called the *interactivity principle*. Accordingly, engaging students with the educational content at hand is key. BA accomplishes this through the gradual unveiling of additional components as students learn more concepts and discover more of the town and its underlying hydrogeologic features. Student teams control the pace and direction of their explorations to varying degrees depending on the course level in which BA is implemented.

Some researchers suggest that using simulations and educational games can be an effective way to engage the "video game generation" (Katz 2000, Prensky 2006). Researchers in recent years have also found that the learning and engagement seen in young people's playing of video games, including simulation-based games, can be translated into meaningful educational gains in the classroom (Shaffer et al. 2005; Gee 2003; Rieber 2001, 2004, 2008; Prensky 2006; Herrington et al. 2007; Van Eck 2007; Chinn 2002). Simulations also allow the packaging of complex issues into consistent narratives, which can facilitate meaning-making (Bruner 2002; Weinberger et al. 2005). They have also been found to be an effective way to represent complex systems and explore multifaceted sociotechnical problems (Gee 2005; Squire and Jenkins 2004; Barab et al. 2005; Rosenbaum 2007; Herrington et al. 2007). Learners are able to understand educational content by exploring it within realistic situations, consistent with the principles of situated learning (Lave and Wenger 1991; Barsalou 1999; Pedretti 1999; Barab and Plucker 2002; Rosenberg 2006). Through its use of a complex narrative with interactive videos and maps as well as environmental testing tools and other game-based features, BA takes advantage of the motivational features of games to engage students in the narrative of an environmental contamination event that weaves in a system of scientific skills and concepts.

Simulations also allow educators to move away from large lecture halls, where students are typically passive, and increase participation through inquiry-based learning. However, the role of teachers in scripting and facilitating simulation-based activities remains crucial (Barab et al. 2000; Weinberger et al. 2005). While measurable benefits of educational simulations have been shown to vary according to prior knowledge, the medium has been shown to positively impact comprehension, cognitive load and learning efficiency (Park et al. 2009). BA is particularly adaptable to students with high and low prior knowledge because the nature and amount of assignments can be modified and because contextual help provided by instructors can be tailored to the appropriate level of the intended audience.

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Technology can have powerful effects in putting constructivist principles into practice. A truly useful multimedia-supported learning environment must present the nuts and bolts of the discipline being taught, provide a realistic context in which those basic principles operate, and allow students to explore the forms, relations, and implications of the data they encounter. Most importantly, the simulation should embody a rich and complex narrative — ideally including conflicting threads of information to unravel and false leads to decode — in which students must solve substantive problems, occupy constructive roles, overcome hasty judgments, and resolve ambiguity. In BA, the level of complexity increases during the

semester-long inquiry, giving rise to ambiguity. Because there is no set of fixed outcomes, ambiguity is a fundamental component of BA as well as real-world investigations. This crucial feature is absent in most traditional, well-designed, laboratory science exercises, which often take a "cookbook" approach to learning — that is, if the instructions are understood and followed, students know there is a solution that can be achieved before the end of the lab period. Awareness of this ambiguity is an important pedagogical tool as students try to reverse "cookbook" expectations, deal with the insecurity of ambiguity, and find threads that lead to real solutions.

Not surprisingly, the inquiry-based approach of BA produces conflicts with previously learned student behaviors that accompany traditional, didactic methods. For example, students often become frustrated when outcomes do not provide the immediate sensation of being done or with a clear sense of the end in sight. Furthermore, student work habits typically involve spikes of effort revolving around the next test or assignment. For continued success in BA, students must own, internalize, and utilize concepts and information beyond the next test or assignment. There are many paths to discovering the hidden reality embedded in the simulation, but, regardless of the path chosen, BA requires consistent and persistent effort without the stimulus of continuous due dates or deadlines. Students, thus, begin to also understand and own the process and difficulties of their own education.

BA is also exceptional in that it is designed to foster a respect for learning by placing students in a learning environment that insists that they gain ownership of the aptitudes for analysis, the competence in the demanding discipline of an environmental site assessment, the expertise to employ a variety of analytical methods to respond both critically and creatively to the simulation, and the ability to promote and advance the effectiveness of teamwork within the student companies. These pedagogical issues are raised with students directly both in lecture and laboratory in an effort to raise their awareness about their eventual transition to the challenges of life beyond the college classroom.

The BA laboratory experience also supports student learning. Lab sessions are designed to be seamless, integrated, and continuously evolving from one lab to the next, and because the BA simulation is network-based, student companies can continue their work during the week anywhere there is Internet connectivity. More importantly, laboratory exercises for BA are integrated into the simulation and, thus, need to be understood in the context of new information and reevaluated in the context of a final report to the development corporation. For example, a standard lab exercise involving the sieving of sediment and the determination of particle-size distributions and porosity becomes in BA an investigation of sediment from a drill hole at the abandoned factory. The porosity data from this analysis must be combined with permeability data determined in a subsequent laboratory and with an understanding of D'Arcy's Law to calculate groundwater velocity. This calculation is important for predicting and understanding the nature and extent of the contaminant plume but also for legal, forensic, and planning purposes. Thus, students must not only learn about particle-size distributions, porosity, permeability, and D'Arcy's Law but must also own this information in order to use it in the context of their investigation and final report.

Finally, BA is unique in that it accurately replicates a real-world experience for students. At the beginning of BA, students are told that their education will be defined by those aspects of the experience that they "own" and are able to use to influence their lives six months after the course is over. The problems posed in BA cannot be solved without the knowledge component, but BA puts content into motion as it is actually used in the real world. To succeed in BA, students must acquire and administer problem-solving skills associated with a range of activities and professional roles as:

1. *Journalists* or, students must assess the credibility of information provided by a cast of characters who have conflicting motivations and different levels of knowledge, navigating their way through a complex tableau of fragmentary information and partial truths.
2. *Environmental scientists and engineers*, students must study the relevant techniques, such as ground-penetrating radar and soil gas analysis, and use them judiciously.
3. *Business managers*, student companies must make decisions about the relative value of all available investigative procedures, complete their ESA, and maximize profit.
4. *Public health professionals*, students must investigate the possible medical consequences of a toxic event and assess and substantiate claims about a causal link between individual medical cases and the contamination.
5. *Citizen activists*, students must understand basic civics and the law and be politically savvy as they interpret public records, gather information for possible indictments, form recommendations about the steps required to remedy

environmental damage, and make decisions that reflect values associated with land use, private property rights, and public welfare.

This interdisciplinary approach represents a more practical and realistic picture of the utility of science in today's world. Because BA is an investigation of environmental contamination and takes place within a simulated city with actual people, the central theme of the semester is one of civic engagement. Brownfields, environmental site assessments, and toxification of the environment are of concern to everyone. The combination of the motivation of civic engagement with science in a realistic context allows BA to show how to "bridge the gap" between the "two cultures" and bring the scientific and non–scientific communities together (Burns and Holt 2009).

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Those interested in exploring the simulation in more detail and learning how other instructors have utilized BA should visit brownfieldaction.org, and contact the site administrator to obtain a password.

About the Authors

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Frank Moretti has thirty-nine years of experience in school-based leadership and is recognized as one of America's leading theorists and practitioners in the use of digital technology in education. He was the executive director of the internationally known Dalton Technology Plan. He founded the software company Learn Technologies Interactive. He is currently the co-founder and executive director of the Columbia University Center for New Media Teaching and Learning and professor of communication and education at Teachers College, Columbia University. He received his Ph.D. in history from Columbia University. Columbia University, CCNMTL, 2970 Broadway, Mail Code 4122, New York, NY 10027, fmoretti@columbia.edu, 212-854-1692.

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