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The Theatre of Humanitarian Engineering

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David DiBiasio is Associate Professor of Chemical Engineering and Department Head of ChE at WPI. He received his ChE degrees from Purdue University, worked for the DuPont Co, and has been at WPI since 1980. His current interests are in educational research: the process of student learning, international engineering education, and educational assessment. Collaboration with two colleagues resulted in being awarded the 2001 William Corcoran Award from Chemical Engineering Education. He served as 2004 chair of the ASEE ChE Division, has served as an ABET program evaluator and on the AIChE/ABET Education & Accreditation Committee. He has also served as Assessment Coordinator in WPI's Interdisciplinary and Global Studies Division and as Director of WPI's Washington DC Project Center. He was secretary/treasurer of the new Education Division of AIChE. In 2009 he was awarded the rank of Fellow in the ASEE, and in 2013 was awarded the rank of Fellow in AIChE.

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Through her role as Associate Director for the Center for Project-Based Learning at Worcester Polytechnic Institute, Paula Quinn works to improve student learning in higher education by supporting faculty and staff at WPI and at other institutions to advance work on project-based learning. She believes project-based learning holds significant potential for increasing the diversity of students who succeed in college and who persist in science, technology, engineering, and math (STEM) fields, and she views her work with the Center as contributing to education reform from the inside out. She holds an M.A. in Developmental Psychology from Clark University and a B.A. in Psychology from Case Western Reserve University. Her background includes working in the field of education evaluation, where she focused primarily on the areas of project-based learning; STEM; pre-literacy and literacy; student life; learning communities; and professional development. She has worked on projects whose funding sources have included the National Science Foundation, the Institute of Education Sciences, and the U.S. Department of Education.

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Kristin Boudreau is the Paris Fletcher Distinguished Professor of Humanities and Head of the Department of Humanities and Arts at Worcester Polytechnic Institute. A scholar of nineteenth-century American literature, in recent years she has turned her attention to transforming engineering education by contextualizing engineering challenges in their historical, cultural, geographic and political settings. Recent publications in this field include "To See the World Anew: Learning Engineering Through a Humanistic Lens" in Engineering Studies 2015 and "A Game-Based Approach to Information Literacy and Engineering in Context" (with Laura Hanlan) in Proceedings of the Frontiers in Education Conference 2015. A classroom game she developed with students and colleagues at WPI, "Humanitarian Engineering Past and Present: Worcester's Sewage Problem at the Turn of the Twentieth Century" was chosen by the National Academy of Engineering as an "Exemplary Engineering Ethics Activity" that prepares students for "ethical practice, research, or leadership in engineering."

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Professor John Sullivan joined WPI in 1987. He has had continuous external research funding from 1988 thru 2013. He has graduated (and supported) more than 75 MS and PhD graduate students. He has served as the ME Department Head and in 2012 was elected Secretary of the Faculty through 2015. Prof. Sullivan has always maintained a full teaching load. He strongly supports the WPI project-based undergraduate philosophy.

Prof. John Bergendahl, Worcester Polytechnic Institute

John Bergendahl is an Associate Professor in the Department of Civil and Environmental Engineering at Worcester Polytechnic Institute. He has six years experience as a practicing engineer in industry, and holds a B.S. in mechanical engineering, an M.S. in environmental engineering, and a Ph.D. in chemical engineering; all from the University of Connecticut. His recent research efforts are primarily directed at investigating novel treatment methods for emerging contaminants, and the development of systems and methods to sustainably treat water and wastewater.

Leslie Dodson, Worcester Polytechnic Institute

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Abstract

An experimental role-playing course designed by an interdisciplinary team of faculty from engineering and the humanities puts students imaginatively into a complex nineteenth-century context as they consider how to provide a waste management solution for an expanding urban population. This role-playing game (RPG) puts students in the roles of actual people living in a turn-of-the-century industrial city in central Massachusetts. While immersing themselves in the roles of engineers, industrialists, elected officials, workers, scientists, public health officials, inventors, and city residents, students learn and practice engineering concepts (engineering design, stakeholder analysis, mass balance, sewage treatment, material properties and selection, sewage properties and conveyance, statics and stress, filtration and chemical precipitation, and so on). These engineering concepts are not abstracted from social, political, and economic considerations. Rather, engineering is imbued with social context. The RPG offers students opportunities to reflect on economic, geographical, economic, and philosophical issues while learning the technical skills they need to make informed decisions to address the needs of a rapidly expanding population.

Introduction and Statement of the Problem

In 1945, when the French mathematician Jacques Hadamard sought to uncover the thought processes of mathematicians, he approached Albert Einstein, who suggested that "combinatory play seems to be the essential feature in productive thought."[1] For many years, educators have tried to design curricula that foster this associative learning —which, we know from our own experiences, is how we learn best outside of the classroom. Twenty-first century engineering educators have been mindful of ABET's EC2000 student outcomes a-k, including ethical understanding, the ability to communicate effectively, and "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context."[2] Engineering educators who struggle to help students achieve these ABET learning outcomes might consider working together with liberal arts faculty to integrate engineering with humanities understanding. What the environmental historian William Cronon wished for liberal arts education is equally sought by engineering educators: "Only connect."[3]

And yet our institutional environments discourage this "combinatory play" of disciplines, methods, and ways of thinking. The traditional means of integrating engineering and the humanities is through general education requirements, which students tend to take during their first two years, in lower-level survey courses. Here they learn a bit about history, writing, or philosophy, with the hope that they will remember and draw on this work once they dig into their major coursework and projects. But most of these lower-level general education courses focus on delivering content, often in large lectures.[4] The methodology of the discipline, and opportunities for students to understand how a historian or philosopher or writer thinks, are reserved for history and philosophy and literature majors in their more advanced classes. In the general education curriculum, integrative learning is little more than a fantasy. For the engineering student, this approach often leads to compartmentalized learning, where students do not connect their general education courses to their engineering courses.

When it comes to integrating engineering and humanities within a single course, the prospects are more promising but the effort much more daunting. Engineering and the humanities are so far removed from one another —sometimes quite literally situated on opposite ends of large campuses, in separate colleges and institutional environments that make it difficult for faculty to meet one another, let alone collaborate. Without collaboration, integrative learning depends on a single professor who is able to span the large gulf between engineering and the humanities. Engineering programs that are situated in smaller institutions with strong liberal arts environments are better poised to bridge this disciplinary divide, as are institutions with programs in Science, Technology, and Society. Opportunities like Union College's annual Symposium on Liberal Arts and Engineering, the Kern Foundation's Kern Engineering Entrepreneurship Network, the ASEE's Teagle Foundation-funded Engineering Enhanced Liberal Education Project, and this division of the ASEE help demonstrate the best of this liberally integrative approach to engineering. But however rewarding it is to collaborate across disciplines to develop innovative integrative courses, it is difficult for many engineering faculty to make these connections in the first place. The impediments to deep and authentic integration within the disciplines —whether in engineering or humanities courses— are difficult to overstate. True integration is most likely to happen in institutions where engineering faculty work in close proximity to humanities faculty. These interactions can happen at smaller liberal arts universities with engineering schools or departments, like Union College, Lehigh University, and Bucknell; in programs designed to bring together humanists and engineers, like UC Boulder's Herbst Program of Humanities in Engineering; in institutions that embed humanities faculty within technical departments, as at Arizona State University; and at primarily technical institutions with strong programs in the humanities, like MIT, Olin College, and WPI.

The course we describe may seem an unpromising topic for first-year students looking for an engaging class. "Humanitarian Engineering Past & Present: Worcester, 1885" asks students to spend the term scoping a sewage treatment problem and determining who suffers and benefits from the open sewer that runs through the city of Worcester, its frequent sewer overflows, and the human and industrial waste that makes its way into the Blackstone River. They learn about the composition of sewage and the different ways of treating sewage available in the late nineteenth century. They assume roles and debate whether the city should address the problem or accept the (legally permissible) status quo. Once they receive news that the Commonwealth of Massachusetts will require Worcester to address the problem, they form teams to propose a solution. They spend a lot of time thinking about human waste and how humans interact with it. And yet we have seen that students enjoy the novelty of assuming a role and learning engineering design from a nineteenth-century point of view. As one student put it, the exercise of working with multiple stakeholders on an engineering problem "can be stressful, challenging, and at the same time exciting. But I feel *ready* for it!"[5]

Background

"Humanitarian Engineering Past and Present" is an experimental first-year course designed and taught by an interdisciplinary team of faculty from engineering, humanities, and entrepreneurship and innovation at Worcester Polytechnic Institute (WPI), a technology-focused private university in Worcester, Massachusetts. WPI is best known for its 47 year-old project-based curriculum. Since 1970, all WPI undergraduates have been required to complete three major projects: a 3-credit self-directed project undertaken in some discipline of the humanities and arts and completed after 15 credit hours of humanities and arts coursework; a 9-credit junior-year interdisciplinary project on a topic at the intersection of technology and human needs; and a 9-credit senior-year project in the major. For all these projects, students work alone or in teams on an open-ended problem that requires contextual thinking. The most innovative of these three projects —as well as the project that has taken the most assessment, redesign, and support over the years— is the junior-year interdisciplinary project, called the Interactive Qualifying Project or IQP. This project, in many ways the inspiration for the course we describe here, is a model of integrative learning because projects typically include two to four of the following attributes:

- Examine impact of social issues on technological systems;
- Examine impact of technology on social structures;
- Cultivate questioning of social values and structures;
- Raise value questions about social/technological interactions;
- Develop skills of analysis in the societal, humanistic and technological disciplines;
- Recommend policy changes in social/technological interactions;
- Convey technical content to a novice or non-technical audience.[6]

WPI's junior-year IQP requires design thinking, which itself draws on both technical and cultural understanding and is therefore a deeply and authentically integrative learning experience, one that has significant positive impacts on students' personal and professional abilities.[7] However, this curriculum has taken 47 years to refine, is time-consuming to implement, and requires both a strong support infrastructure and small student-to-faculty ratios.[8] Most institutions would find it impossible to implement. We were motivated by the challenge of making these learning outcomes available to students at institutions without the resources to provide projects like ours. Could the student outcomes of the IQP be achieved in a more traditional classroom setting through a role-playing game (RPG) based on an actual, complex, open-ended problem like the ones at the heart of WPI's junior-year projects?[9] This was the question we sought to answer when we designed the course "Humanitarian Engineering Past & Present: Worcester, 1885."

Our course puts students in the roles of actual people living in a turn-of-the-century industrial city in central Massachusetts. Students learn and practice engineering concepts (engineering design, stakeholder analyses, mass balance, sewage treatment, material properties and selection, sewage properties and conveyance, statics and stress, filtration and chemical precipitation) while playing the roles of engineers, industrialists, elected officials, workers, scientists, public health officials, inventors, and city residents. If WPI's IQP was one inspiration for our role-playing game (RPG), so was the popular Reacting to the Past (RTTP) series of games developed by Mark Carnes and colleagues from Barnard College.[10] Carnes developed these RPG historical games based on the idea that competition and "subversive play" would help inspire student engagement in history. Although for many years these RTTP games were designed for humanities classrooms, in recent years they have expanded to include STEM.[11]

Approach: The Course and Our Use of Theatre

Although nearly 72% of WPI undergraduates are engineering majors,[12] we designed "Humanitarian Engineering Past and Present" to provide a deep integrative learning experience of benefit to both STEM and humanities students, and it is our hope that it will be used in liberal arts as well as technical institutions. The course brings together history, theatre, and engineering in such a way that most classes and homework assignments pursue our learning objectives in a transdisciplinary way, with authentic disciplinary content from both the humanities and engineering. Our primary means of doing this is to assign each student a role to play for the duration of the course and to ask that student to consider the challenges and assignments of the course —and of Worcester's nineteenth-century waste-management problem— through the lens of his or her particular character role. All roles are historically accurate. About a quarter of the roles are engineers, for example: Colonel George Waring, a sanitary engineer who held many patents, including one for the separated sewer system that he designed for Memphis; Frederick McClure, Worcester's City Engineer; Harrison Eddy, Worcester's Superintendent of Sewers, and other similar historical figures. Several others are health professionals: Doctor Robert Booth, a general practitioner living and practicing in the town of Millbury, MA, downstream of Worcester; William T. Sedgwick, a bacteriologist at the Massachusetts Institute of Technology; Ellen Swallow Richards, an industrial and environmental chemist working at the Lawrence Experiment Station; and Dr. Lemuel Woodward, Chairman of the Worcester County Board of Health. Others are industrialists (factory owners living in Worcester and downstream on the Blackstone River) and ordinary working people in Worcester County, including Irish immigrants, African Americans, clergy, factory workers, teachers, and working-class people living near the open sewer.

Like many courses, our first class session is devoted to logistical issues. In our case, we spend time discussing with students our pedagogy, particularly with reference to the "Engineer of 2020." In fall 2016 we gave particular emphasis to this point because our students were entering as members of the Class of 2020. The National Academy of Engineering has identified the following attributes as essential for the Engineer of 2020: strong analytical skills, practical ingenuity, creativity, communication, an understanding of business and management, the principles of leadership, an ability to practice high ethical standards and professionalism, and the ability to adapt quickly to a changing world, including dynamism, agility, resilience, flexibility, and the capacity to be lifelong learners.[13]

Their first assignment introduces students to the research skills needed to understand their roles as well as to the digitally available historical materials that will orient them spatially to the sewage problem. Students receive a role sheet that includes historical resources (see Appendix). In addition, we ask them to conduct additional research into their role, using these early resources as a point of departure. We expect them to use Google as their first and primary search tool, though we give them no guidance as to research methods. We do, however, provide a number of digital resources and detailed instructions for navigating them. We ask them to find their character in the 1885 Worcester City Directory, an annual catalog of Worcester residents, including their street address, age, and occupation. Next, they must locate their character's places of residence and employment on the 1886 Worcester City Atlas, which WPI students have digitized from bound volumes held at the Worcester Historical Museum. Because this atlas is interactive, users may zoom in and out at high resolution, making it possible to travel virtually around the city and imagine the geographic movements of their characters in the course of a day or a week. They also have access to an 1878 birds-eye view of Worcester —a stylized aerial view of the city that was popular in the nineteenth century. Here they can see representations of the city's architecture and get a less detailed but more sweeping sense of the city and its neighborhoods, its waterways, streets, industrial buildings, parks, residences, churches, farms, and dense neighborhoods. After they find their way around the map and begin to imagine their character's daily movements, we ask them to post a screenshot of their character's residence and place of employment to our class Blackboard site. In addition, all students must read the 1867 "Act Concerning Sewers and Drains in the City of Worcester," which permitted indiscriminate dumping of waste material into any body of water. We want our students to begin thinking about right, wrong, and the distinctions between law and ethics.

To draw the "magic circle" —the line that distinguishes the world of our game from the real world of our students' lives— we begin with the dramatic discovery of a dead body floating in the Blackstone Canal.[14] Like RTTP games, our RPG includes a few counterfactual events: these are events within our game that, while historically plausible, never in fact happened. The discovery of this dead body is one such counterfactual event: it might have happened but we don't know that it did. Nevertheless, it helps us draw that stark distinction between the world outside our classroom and the nineteenth-century world of our game. We print nineteenth-century broadsides and send in a newspaper carrier to announce the discovery. The local Catholic priest, indignant at the news, calls a mass meeting and urges his townspeople to attend.

The mass meeting is another counterfactual event, but it helps us teach students how to determine the scope of the problem. Worcester's wealthy residents, living in the hills of the west side, may not believe there is a problem at all. But for the working people living near the open sewer in the Irish neighborhood where the body was discovered, these open sewers are an affront to decency. Medical professionals may have concerns about germs; sanitary engineers may be troubled by the filth and stench; mill owners downstream of Worcester may be dismayed by the waste that clogs their mills and discolors the water. And so on: there are many stakeholders in Worcester, and the lesson of this mass meeting is that problems may be defined in many different ways, depending on point of view and interest. For our students, the challenge is to speak persuasively and effectively, with both emotion and facts. A mill owner may build a model of his mill to demonstrate the costs of the polluted waters when the machinery gets clogged and operations are disrupted; a resident of the open-sewer neighborhood may gather nineteenth-century information about waterborne illnesses to describe her family's ills; a proponent of the miasma theory of illness may collect his own data and make an argument about the smell emanating from the sewer. In this assignment, students conduct research, make arguments, listen to one another, and begin to understand the complexity of Worcester's sewage problems.

A subsequent meeting focuses on the question of policy —whether to take action based on the evidence presented at the first meeting. This is primarily an ethical debate about whether Worcester should observe an ethical standard higher than the law. Whatever the city officials decide at the end of this meeting, the next class reveals breaking information: a new state law compelling Worcester to address the problem. And so the class turns its attention from the question of whether to act, to now considering the best course of action. These are the role-playing classes where students speak in character from their different points of view, informed of course by their research and ethical, economic, and technical considerations.

We also give students lectures, labs, and assignments on the technical matter they will need to know in order to propose a solution by the end of the course. For instance, once it becomes clear in the game that no action is not an option, players must quickly learn about waste treatment in order to decide upon a particular course of action. An early lecture on sewage properties, taught by our civil engineer, John Bergendahl (playing the role of Joseph P. Davis[15]), covers the composition of sewage: its color, turbidity, and organic content. In preparation for this lecture and lab, students review a spreadsheet containing data from a state board of health's analysis of Worcester's river water, and then to help them interpret those data they read a chapter from Metcalf and Eddy's 3-volume *American Sewerage Practice.* (Another counterfactual: although this textbook was not published until 1915, we understand that much of its content was knowledge generally held by the leading sanitary engineers of their day, including Davis.) In lecture students learn how turn-of-the century civil engineers collected and tested sewage samples for their qualities: using an Imhoff cone to measure "settleable" solids and using the best practices of the day to quantify the appearance of sediment. (Engineers used imperfect descriptions, including "very slight," "slight," "considerable," and "heavy.") During our lab we discuss the errors that are built into this subjective system of analysis and talk about how best to mitigate variations. (In the second term of the course, when we turn to the contemporary context, students learn how to measure turbidity using modern instruments that accurately quantify the amount of light that passes through a liquid. In this way they learn to ask questions about the limitations of scientific knowledge and tools and to begin thinking about science and engineering as processes that can always be improved. They may be surprised to learn that, despite its limitations —which have been improved in revised editions— the Metcalf and Eddy textbook remains the definitive source on sewerage practice.)

Soon after the sewage properties lecture and lab, students hear from their chemical engineering professor, David DiBiasio (in character as Prof. Leonard Kinnicutt), for an introduction to sewage treatment.[16] Here they see some of what they learned in the sewage properties lab, but now they consider sewage treatment as an entire process. In preparation for the class, students read a paper on sewage and sewage disposal presented by Kinnicutt to the Massachusetts Boards of Health in 1890. The article helps them understand what was known about sewage treatment in 1890. Kinnicutt's paper introduces the concept of an integrated process and includes some of the numbers needed to understand mass conservation, so students recognize the need to balance quantities; this is a point that Prof. DiBiasio stresses in his lecture. Moreover, because this reading includes the minutes of a discussion that followed Kinnicutt's reading, we are able to follow some of the debates among engineers and public health professionals. Because students are considering the course content from their characters' perspectives, this discussion helps them understand that science and engineering are professions with their own cultures and controversies. In this way, a single lecture plus reading demonstrates both the scientific and the humanities content of sewage treatment. In his lecture, DiBiasio reviews a process diagram from Worcester's early waste treatment plant in order to understand how different processes connect. Students learn how an integrated set of single-unit operations (filtration, precipitation, sedimentation, sludge treatment) combines to produce clear water for discharge into the Blackstone River. (Once again, students in the second term, present-day component of the course will have a chance to compare present-day processes with turn-of-the-century processes, this time when they tour the Upper Blackstone Wastewater Treatment Facility. Students are always impressed with how complex and beautiful the modern-day facility is; we faculty are likewise impressed with how much it resembles what Metcalf and Eddy describe in 1915).

In the final weeks of the course, students form teams to propose solutions to Worcester's sewage problem. We ask them to consider how their character would feel about the proposed solution and how they will address the needs of other characters they learned about through the RPG. Each team is assigned one of the prevailing options of the day: broad irrigation, chemical precipitation, intermittent filtration, and the separated sewerage system developed by Col. George Waring. Each team develops a poster and a five-page written report that includes an introduction, problem statement, summary of progress toward the design, background on the solution, justification, and references. Reports call on the full spectrum of the humanities and engineering content and approaches that students have been learning all term. What we did not expect (but perhaps should have, given the interactive nature of the role-playing all term) was that on the final day of class, as student teams presented their recommendations, a bit of spontaneous verbal sparring erupted between teams. Since each team was surveying the competition and advancing arguments for the superiority of their approach, it made sense that their audience, mostly competitors from other teams, should want to promote their own solutions by way of challenging their opponents. We plan to take advantage of this discovery next time, moving from a formal poster presentation to a managed debate.

Discussion

Our use of theatre through role-playing brings together humanistic and engineering learning in the context of a complex problem within the rapidly expanding, heterogeneous, nineteenth-century context of Worcester, Massachusetts: a city whose heterogeneity in many ways represents the challenges that contemporary engineers face. In some cases, students are naturally drawn to the role-playing activities: some of them have performed in theatrical productions or have immersed themselves in role-playing games like *Dungeons and Dragons*. We have seen students who embrace the opportunity to behave differently than usual, particularly introverts who become animated and intense when inhabiting a role. Of course, not all students enjoy acting. We are careful to arrange informal opportunities for them to get used to their role out of the spotlight of the entire class. Although they are expected to *perform* their roles during in-class debates and mass meetings, they also take part in lower-stake interactions, introducing themselves to other characters in small groups, getting to know other characters and getting comfortable in their own roles. In these less formal interactions as well as in online interactions (through our class website), students practice imagining the lives, values, and perspectives of people very different from themselves. Those who are uncomfortable with theatrical performance have many chances to inhabit their roles.

While theatre gives students a different way to approach their learning, it also introduces them to some of the important but caducous learning outcomes that the engineering profession values but cannot always teach. We discuss some of those outcomes below.

Empathy

Empathy, the first step of design thinking, can be difficult for many of us to achieve. However sympathetic our students may be, empathy requires them to see the world through a different perspective than their own. This means not merely feeling sadness for vulnerable people (which many young people do well) but actually thinking about how the world presents itself to these people. By digging deeply into their roles and thinking of the course content through the persistent lens of their character role, students learn what it means to identify with another person, even a person at some considerable historical remove. But they must identify not only with their own roles; to do well in this game they must also learn to listen well. Thus, at times students are asked to identify simultaneously with multiple stakeholders. They quickly learn that professional affiliation does not always mean a singular point of view: a factory owner in Worcester may oppose a major sewerage overhaul because he fears disruption of his business, while a downstream mill owner may depend upon a major engineering project to clean the river he uses for waterpower. Even within the engineering profession students discover rifts, like those between formally trained engineers, especially those holding faculty positions, and self-made engineers who have more in common with businessmen, even charlatans, in their rush to sell their product. And the practical city employee who thinks he stands on firm ground by reminding audiences that Worcester's use of its waterways is perfectly legal may be stunned to hear a moral argument from a Catholic priest who has read and been moved by Thoreau's powerful essay, "Resistance to Civil Government." In a class discussion at the end of this term, we heard from several students that they enjoyed learning about social justice, the struggle for workers' rights, and they particularly liked reading the short autobiography of the Chicago Haymarket anarchist George Engel, whose frustrations trying to make a living through hard work they found quite moving.

Information literacy and research

Students also spend time out of class researching their roles, showing deep engagement with the practice of research, and they learn the immediate and profound benefit of thorough research. An early discovery led us to conclude that even as they conduct much more research in this course than in other first-year courses, students seem surprisingly engaged in their research.[17] Student projects at the end of the term indicated strong performance in finding and evaluating historical documents, both technical and cultural. We achieved this outcome by involving a research and instruction librarian in course planning and instruction, and by working into her instruction some of the topics that our students were already pursuing in their roles. For instance, nineteenth-century engineers and public health professionals were divided over the question of disease etiology. Although the introduction of medical bacteriology in the 1870s should have put to rest the miasma theory of disease transmission, it took many years for this older theory to die, in part because of the very partisan efforts of many engineers, including Col. George Waring, a character in our RPG. But it is difficult for first-year students to find their way in this debate without guidance, so we used the topic of "sewer gas" for our first information literacy session with the librarian. Early in the term we assigned a short reading on the history of sewer gas, a phenomenon associated with the miasma theory.[18] In her introduction to information literacy and research, our librarian, Laura Robinson, asked students to review the footnotes in this reading and track down the nineteenth-century sources using available databases, including Google Books, New York Times Historical, JSTOR, and Engineering Village, which include nineteenth-century sources. Students then search for other nineteenth-century sources regarding sewer gas, learning to limit their searches by date and using advanced search tools. They try to find the full texts of these articles. While she is teaching them about how to find sources, Robinson's choice of topic also enables her to teach valuable lessons about the changing status of scientific knowledge and the importance of using judgment when reading articles. The result was that students, already thinking about the topic of sewage and public health, were visibly engaged in the exercise of trying out different databases. That engagement continued throughout the term, with demonstrable results in their five-page proposals at the end of the term.

Communication

Public speaking, of course, is another important outcome of our theatrical activities. Before the big classroom debates and mass meetings we spent a few minutes with our students, getting them comfortable with their voices and with stepping out of their comfort zone. One exercise required each of us (faculty included) to choose a spot against the wall. Facing the wall, we were all asked to think of a sentence and whisper it three times into the wall, then shout it three times in our loudest voice, then say it seductively, then say it as if to our grandmother, and so on. Of course there was plenty of giggling, but the exercise warmed us up, broke down inhibitions, helped us clear our throats and prepare to whisper or shout or speak in whatever voice might be most effective. In this way we all relaxed, had a laugh, got comfortable with each other, and prepared for our performances. We heard from some of our students that when they had presentations to give (in other classes as well as ours) they sometimes used these exercises to "psych themselves up" and prepare for the oral presentation. We don't know if poster presentations and debates were easier in character, but we do know that by regarding these presentations as a performance, students were able to throw themselves into the presentations in a way they would not if performing as themselves.

Collaboration

Finally, in researching and playing their roles, our students also learn to collaborate. Engineering and theatre both depend on teamwork —the ensemble or the team do not shine unless each individual shines, and individual performance is worthless if it only shows up the shortcomings of other performances— so students learn to be part of a larger organism in their interactions and assignments. Although the second term put aside the role-playing in favor of working as themselves on problems in the contemporary world, the role-playing of the first term helped students to think of themselves as part of a collective, even and especially when they were debating and trying to win against an opposing team.

Assessment

Our alpha- and beta-phase assessments consist of frequent student reflections, including discussions in class at the end of interactions, end-of-term reflective essays, end-of-term focus group discussions, a pre- and post-course scenario that students respond to in informal writing assignments, and a Student Assessment of Learning Gains survey administered at the end of the term. We report here on one particular assessment that we developed for this class. We alpha tested the instrument on two upper-class students who had taken our course the year before and served as Peer Learning Assistants (undergraduate TAs) in the second iteration of the course. They helped us by doing the assessment activity and reporting back to us on areas of confusion that we subsequently clarified.

For this assessment activity, we distributed informed consent forms to our students and told them that they were free to participate or not participate; we would not be present in the room and would not know the identities of the participants until after submitting final grades for the course. Participants agreed to take part in a 30-minute activity requiring them to work in teams and be videotaped. In return, they would each receive $30 worth of merchandise from the campus bookstore, which they could exchange for credit. Of the fifteen students present in class on the final day, all fifteen chose to participate. Graduate students oversaw the activity, which consisted of students counting off by fives in order to form random teams. The graduate students then stayed in the room to be sure the video equipment functioned properly. *Note:* Although we used a randomization process to ensure random selection of teams, after reviewing the videos we discovered that three of the five teams were exclusively male, while the remaining two were exclusively female. However this configuration happened, next time we must take measures to ensure gender heterogeneity among the teams. As we note below, at least one of the competencies we discerned (empathy) appeared in the two all-female teams and only one of the all-male teams. We identify the teams as follows: F1 and F2 (all-female teams), M1, M2, and M3 (all male teams).

All student teams were given the same photo and brief scenario. The photo was one of Dorothea Lange's less widely recognized images of Dust Bowl migrant families. The instructions asked students to determine what they could about the conditions of this family in order to recommend interventions that would improve their lives. We purposefully gave few details and left the kind and extent of intervention completely open-ended; this was to encourage students to think as broadly as they could. The assessment consisted of two sets of instructions, to be completed in two parts:

1. Working as a team and drawing on the brief description and photo that have been provided as well as your experiences in this course, please identify and list the questions you will ask the staffer who conducted the original site visit.

2. After developing your questions, you learn that the worker who conducted the site visit will not be available to answer them until after your assessment is due. A deadline extension is not possible. Given these new conditions, based merely on the photo and brief description you have, think broadly and indicate whether this is a place that could benefit from some kind of intervention. If not, explain why not. If so, explain what type of intervention(s) you would recommend.

Our preliminary findings indicate a strong grounding in **collaboration** for all teams and individuals; strong evidence of **empathy** among some (but not all) teams and individuals; and varying degrees of learning that **integrates the humanities and engineering.** We summarize our findings below.

Collaboration: All teams and individuals appeared to be engaged. Individuals seemed to have roughly equal contributions in terms of time on task and specific contributions. All teams demonstrated appropriate teamwork. People listened to each other, responded to each other appropriately, and seemed to value others' contributions. There was little or no domination by any single person or pair of persons, no denigrating of contributions, or other negative behaviors. We saw strong evidence of cooperation and collaboration. All teams worked well together, seemed engaged in the task, and took it seriously.

Empathy: Three of the five teams demonstrated strong empathy for the people pictured in the photo. Of these three, two teams were exclusively female. These teams (F1, F2, and M2) discussed the emotional as well as physical needs of the people pictured. F1 and F2 discussed the possibility of sexual violence. In addition to providing food, water, and toilets, F2 discussed concern for the emotional health of the people in the photo ("they look unhappy"), and addressed the children's happiness (the need for toys, picture books, and art supplies). One student expressed sorrow for the children ("They look trapped"). M2 not only noticed that the children looked "skinny" but also wondered what games they like to play. As one participant put it, "it's an important developmental time in their lives. They need to . . . have their experience lightened." A fourth team, M3, expressed empathy in an indirect way, as frustration over the lack of details given in the scenario description. One member of the team said, "Based on this grainy, black and white photo, we're gonna determine if this family gets funding or not. . . It's almost kind of scary. Like, they didn't look sad enough in the photo, so we're not gonna give them funding." Another teammate responded: "It sounds like an organization that just doesn't want to actually invest in, or, you know, they don't have enough—." Of the five teams, one (M1) focused almost exclusively on the question of housing, how to provide and pay for housing, where to put it, etc. This team offered very little discussion of the people in the photo. And, in spite of our having spent some time during the course discussing safety issues for women and girls who have no private place to defecate, none of the male teams mentioned the safety of this family.

Integration of humanities and engineering: In nearly all cases, students demonstrated the capacity to think through a problem using resources and ways of thinking drawn from both engineering and the humanities. Even M1, who focused almost exclusively on the people's physical circumstances —most extensively, their lack of a permanent house— wondered about whether a loan or an outright grant might offend the pride of the people under consideration. Another group (M2) wondered about the culture's hierarchy. Disappointingly, two teams did not mention sanitation, although that had been the focus of our course.

The video assessment described above gave us a direct evaluation of student learning. Additionally, we also employed an end-of-course survey that prompted students to reflect on their own evaluation of the role-play activities. There were six prompts with a Likert response scale from 1-5 where one=not at all, three=somewhat, and five=very much. For example, students responded to "how effectively did the role-play activities help you learn the material compared to traditional lecture and reading?" with an average rating of 3.6, with 56% rating it at 4 or 5. And, "how effectively did the role-play activities help you understand the combined value of engineering and humanism?" at an average 3.8, with 67% rating it at 4 or 5. Similar results were obtained regarding student engagement in the material, class participation, research abilities, and interest in the course. These indirect results help confirm our preliminary conclusions that role playing is an effective educational activity, particularly in an interdisciplinary context.

Next Steps

Our next steps are twofold: we plan to refine our assessment instrument and RPG materials before the next offering of the class. At the same time, we hope to share our course materials with faculty at other institutions who want to teach and will commit to assessing this course in their own environments. Through WPI's Center for Project-Based Learning we plan to offer workshops in the game design and pedagogy, including test play for participants.

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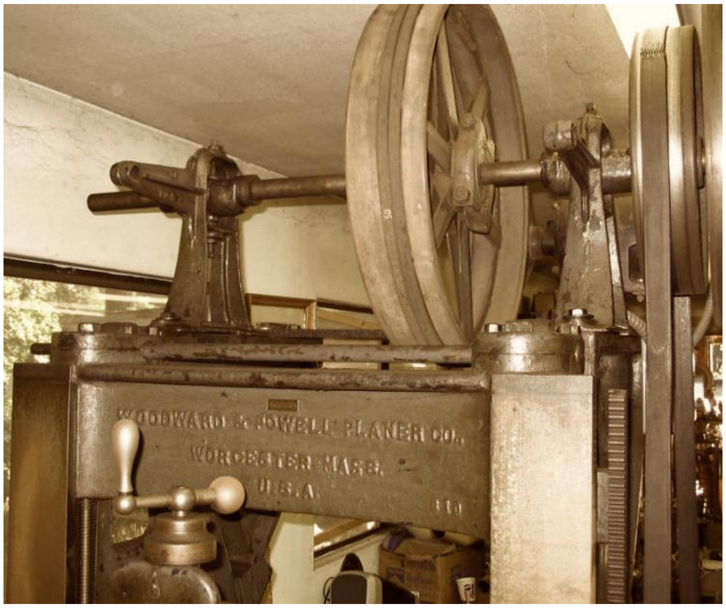
Appendix: Sample Role Sheet

You are Albert M. Powell



Background: You were born in Westville, NY, and remained in Worcester after entering Worcester Technical Institute in 1875 and graduating in 1879. You are a draftsman and mechanical engineer by training. A manufacturer of machine tools, with Edward M. Woodward you established the Woodward & Powell Planer Company in 1887, which manufactured iron planers, shapers, and other machinists tools in the Crompton Building on Cambridge Street. You invented numerous machines for lathing, shaping, and sawing. You were elected to the Worcester common Council (representing ward 7) in 1895. A Republican, you were appointed to the city's Committee on Sewers. You are also a member of the Elks Society. You are a member of the committees on Finance, Fire Department, Sewers, and the Lake Bridge. You are also a member of the Worcester Horticultural Society.

You are a local business owner and elected member of the Worcester Common Council. Your manufacturing company is located on the corner of Cambridge and Fremont Street, near the Blackstone River. You see and smell the polluted waters whenever you enter and leave your factory. However, when you consider that neighborhood, it seems highly industrial and unlikely to change back to the pastoral scene it must have been when the first English settlers arrived. You are a champion of industry and worry that all this talk about polluted waters will threaten to slow down your business, particularly since it is so close to the Blackstone. You will monitor the city map closely to see whether any proposed engineering projects approach too closely your own business. You are particularly concerned that Worcester's industrialists will carry the blame for the foul Blackstone. After so many years of heavy industry and population growth, you can't see how the river will ever be restored to its former purity, and it seems foolish to discuss. As a member of multiple committees in Worcester and a man with many business contacts, you should use these contacts to influence others to help avoid a response that will jeopardize your business at the Planer Company.

Homework and instructions for first session: Learn as much as you can about Worcester's population growth since 1860, since that will be the source of human waste and you will want to point out how much of the sewage problem comes from that source. At the same time, you should also partner with your fellow industrialists, Milton Prince Higgins and Clinton Spaulding Marshall, to learn as much as you can about the content of industrial pollutants in Worcester. In particular, be sure to understand your own industry, what pollutants it produces, and how those pollutants affect the water and air. At the first session, be prepared to defend your factory, but you will also need to listen closely to the concerns of other people. Note where you live and where your business is located, and be considerate of the perspectives of the people whose lives intersect with your own, even if they don't necessarily share your economic interests.

Character Reading:

The Worcester Magazine: Devoted to Good Citizenship and Municipal Development Volume 12 "Woodward and Powell Planer Company" 1909.

Reading to help understand the river pollutants:

Charles G. Washburn, *Industrial Worcester.* Worcester: Davis Press, 1917.

Sources to help understand the work in your factory and other Worcester factories:

Thomas Barber Walter, *The Engineer's Sketch-book of Mechanical Movements, Devices, Appliances, Contrivances, and Details Employed in the Design and Construction of Machinery for Every Purpose. Classified and Arranged for Reference for the Use of . . . All Engaged in the Mechanical Arts. With Nearly Two Thousand Illustrations, Descriptive Notes, and Memoranda.* London, 1890.

You should also browse the advertisements in the *Worcester City Directory:* some of your own planer products are featured there, and you want to be well informed about the products you make and sell.

[1] From Jacques S. Hadamard, "A Mathematician's Mind, Testimonial for *An Essay on the Psychology of Invention in the Mathematical Field*. Princeton University Press, 1945. Reprinted in Einstein, *Ideas and Opinions*. New York: Wings Books, 1954.

[2] ABET, Criteria for Accrediting Engineering Programs, 2016-17.

[3] William Cronon. 1998. "Only Connect . . . : The Goals of a Liberal Education." *American Scholar* (Autumn): 73-80.

[4] The authors are grateful to Benjamin Hurlbut for this insight.

[5] Anonymous student comment in response to one of our term-end evaluation questions: "Putting yourself in the role of someone who is helping to solve an engineering problem, how do you feel about working with multiple stakeholders?"

[6] David DiBiasio and Natalie A. Mello, "Multi-Level Assessment of Program Outcomes: Assessing of Nontraditional Study Abroad Program in the Engineering Disciplines." 2004. *Frontiers: The Interdisciplinary Journal of Study Abroad.* 10: 237-252.

[7] For the impacts of these projects on alumni many years following graduation, see Heinricher, Quinn, Vaz, and Rissmiller (2013), "Long-term Impacts of Project-Based Learning in Science and Engineering." 120th ASEE Annual Conference & Exposition. Paper ID 7159. For impacts of the projects on their professional work, see Vaz & Quinn (2015), "Benefits of a Project-Based Curriculum: Engineering Employers' Perspectives." 122nd ASEE Annual Conference and Exposition. Paper ID 11821.

[8] DiBiasio and Mello, *ibid.*

[9] WPI's project-based curriculum earned four WPI faculty (Diran Apelian, Arthur Heinricher, Richard Vaz and Kristin Wobbe) the National Academy of Engineering's 2016 Bernard Gordon Prize for Innovation in Engineering and Technology Education.

[10] Mark C. Carnes, *Minds on Fire: How Role-Immersion Games Transform College* (Harvard, 2014) describes the pedagogy of the Reacting to the Past series of classroom RPGs that he pioneered in the 1990s. See also http://reacting.barnard.edu

[11] Two full-length RTTP STEM games are part of the Reacting to the Past series and have been published as books: *The Trial of Galileo: Aristotelism, the "New Cosmology," and the Catholic Church, 1616-33; and Charles Darwin, the Copley Medal, and the Rise of Naturalism 1862-1864.* Two other full-length games are in development: Acid Rain in Europe, 1979-1989; and Kansas 1999. In addition, the following chapter-length games (games that require one to three class meetings for game play) are available for classroom use: The Pluto Debate, 1999-2006; USDA Food Pyramid, 1991; Ways and Means, 1935; Puzzling the Carbon Question, 1976; London 1854: Cholera; Climate Change, 2009; Feeding Africa, 2002; Are Atoms Real? —1860 Karlsruhe Conference of Chemistry; European Response to NOx Pollution; European Response to SO2 Pollution, 1984; Diet and the Killer Diseases.

[12] *WPI Factbook 2016.*

[13] *The Engineer of 2020: Visions of Engineering in the New Century*. National Academy of Engineering, 2004 54-57.

[14] Johan Huizinga (1955) describes the “magic circle” as a place apart from the real world, where special rules apply. Games transpire within this circle and depend on a clear distinction from the real world. *Homo Ludens* (1955), 10.

[15] Davis was a civil engineer from New York who was hired by the Massachusetts Board of Health to examine Worcester’s sewer problem and recommend a sewerage system. He recommended a separate system. Students do not need to know his recommendation; for the purpose of our course, Davis is simply a civil engineer with expertise in waste management. This gives our civil engineering professor a role to play that is not far removed from his actual role as professor.

[16] Kinnicutt was a civil engineering professor at WPI and an expert on sewage treatment and disposal during the late nineteenth and early twentieth centuries. WPI students may recognize his name from one of the institute’s largest lecture halls.

[17] See Hanlan, Laura R., Boudreau, Kristin (2014). A Game-Based Approach to Information Literacy and Engineering in Context. Frontiers in Education Conference, 2014 IEEE. Retrieved from: http://digitalcommons.wpi.edu/gordonlibrary-pubs/4.

[18] James Whorton (2001). “The insidious foe” —sewer gas. *Western Journal of Medicine*. Vol. 175(6): 427-428.