EnviroTech: Student Outcomes of an Interdisciplinary Project That Linked Technology and Environment

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Abstract

Within technology education, few interdisciplinary models exist that attempt to simultaneously promote the development of environmental literacy and technology assessment skills. EnviroTech, an online professional development project for secondary teachers, was designed to achieve this mission. This report, the second in a series on the project, describes the interdisciplinary content of the EnviroTech project and the impact it had on the students of 18 middle and high school teachers who participated in the project. The curriculum was set against a consumer decision regarding the purchase, use, and disposal of light bulbs. This scenario enabled the examination of environmental processes (e.g., mercury cycle and bioaccumulation), mercury's impact upon human health, and practices and policies regarding the disposal and recycling of mercury-containing lamps. Teachers employed guided inquiry strategies and several assessment tools (e.g., experimentation and life cycle assessment) to help students hone their technology assessment and decision-making skills. Differences between preassessments and postassessments indicated moderate improvements in students' knowledge of technology, environmental processes, and strategies to protect themselves against mercury exposure. Significant changes occurred in students' attitudes with students reporting greater attention to sustainability issues when purchasing and designing products.

Keywords: Sustainability, interdisciplinary, environmental literacy, life cycle assessment (LCA), technology assessment, decision-making, technological literacy.

Introduction

There are compelling reasons for technology and engineering teachers to build their students' "understandings of the effects of technology on the environment" and to develop their abilities "to assess the impacts of products and systems" (International Technology Education Association [ITEA], 2000). Because these are *Standards for Technological Literacy* (STL #5 & 13), advocates of standards-based educational reform argue that curriculum alignment to national standards is a precondition to assuring that expectations for all U.S. students are consistent. Consumer protection advocates argue that students should develop assessment skills in order to make well-informed consumer choices that will enhance their personal health and safety. Proponents of democracy education point out that a responsible citizenry must be able to weigh the risks and benefits of technological choices so they can better exercise their personal civic responsibilities and take collective actions to bring about structural and policy changes.

The ecologist's focus on the dynamism, interconnectedness, and adaptiveness of systems is also compelling. It emphasizes that humans are dependent upon the earth's ecosystems for life-sustaining *ecosystem services* (Bennett, Peterson, & Levitt, 2005), such as decomposing waste, filtering water, and the pollinating of food crops. It underscores that *environmental stewardship*—acting to maintain diverse and productive ecosystems that are sustainable—is in the best interest of promoting healthy people, a healthy economy, and a civil and just society. Proponents of *environmental literacy* argue that we must "prepare students to understand, analyze, and address the major environmental challenges facing the students' State and the United States" (No Child Left Inside of 2009, Sec. 5622). These students will make complex decisions that demand interdisciplinary knowledge and skills to both analyze and assess complex interactions and to negotiate competing priorities.

Although technology educators have forwarded reasoned arguments to "develop environmental literacy within technology education" (McLaughlin, 1994) and "reorient curriculum toward a sustainable center" (Petrina, 2000, p. 214), survey data suggests that practicing technology teachers may not have had sufficient opportunities in undergraduate teacher preparation programs to develop the prerequisite knowledge and skills to adequately address Standards #5 and 13 (McAlister, 2005). To address these issues, a web-enabled professional development project called EnviroTech was implemented during the spring of 2009 that included practicing technology and engineering teachers across the United States. “The mission of EnviroTech was to develop (1) understandings of environmental processes and systems; (2) skills for identifying, analyzing, and assessing the impacts of technology upon the environment; and (3) skills in the use of guided inquiry, an instructional strategy where teachers structure and scaffold the examination of problems and gaps in knowledge” (Rose, 2010, p. 44). This article, the second in a series, describes the content of the EnviroTech project and the results it had on the students of 18 middle and high school teachers who participated in the project. The first article—“EnviroTech: Enhancing Environmental Literacy and Technology Assessment Skills” (Rose, 2010)—described the impact on teachers regarding learning gains, instructional practices, attitudes, and intentions. The project was made possible through a grant funded by the United States Environmental Protection Agency and Ball State University.

An Interdisciplinary Approach

A review of research within environmental education literature shows the positive outcomes of integrating environmental education into the school curriculum in terms of students’ academic achievement (National Environmental Education and Training Foundation [NEETF], 2000), proenvironmental actions (Rioux, 2011), and critical thinking skills. For example, Ernst and Monroe (2004) examined the influence of an environment-based course on 9th and 12th grade students’ critical thinking skills and dispositions toward critical thinking. The Cornell Critical Thinking Test and California Measure of Mental Motivation instruments were used for gathering data. By employing several control variables, such as pretest scores, GPA, and ethnicity, statistically significant effects of the environmental-based program were found for 9th and 12th grade students’ critical thinking skills. In addition, 12th grade students in these programs had statistically higher dispositions toward critical thinking than did students who were not taking the environmental-based course.

Within technology education, few interdisciplinary courses appear to strike a balance between environmental and technological literacy goals. For example, Coppola (1999) took a principled case study approach to the development of *Society, Technology, and Environment*, an undergraduate course once offered at the New Jersey Institute of Technology. The course was developed around six guiding principles, including engaging students in realistic problems within authentic contexts and providing a rational approach to environmental problem solving. Several controversial cases, such as damming the Hetch Hetchy Valley to provide water to San Francisco, were chosen for their power to highlight the complexities and diverse values that people have relative to the environment.

Perhaps, the most common strategy for integrating environmental content into technology and engineering education is establishing a need for and set of realistic constraints for problem solving, engineering design, and technology assessment activities. In fact, the Accreditation Board for Engineering and Technology (ABET, 2011, Criterion 3) requires engineering programs to document that their graduates have the ability to design a product or process to meet desired needs within realistic constraints, including environmental and sustainability constraints.

The *Engineering is Elementary*® curriculum, developed by The National Center for Technological Literacy (NCTL) at the Boston Museum of Science, offers a clear example of using an environmental problem as a context for engineering design. For example, in “The Best of Bugs: Designing Hand Pollinators” (NCTL, 2007) curriculum elementary children encounter a breakdown in the pollination of a flowering plant when pollinating insects are no longer present. Children learn about the need for pollination in the production of food crops and the roles that flowers and insects play in the pollination process. This backdrop sets the stage for children to design and test hand pollinators against the physical constraints established by models of flowers. Evaluation studies of “The Best of Bugs” (Lachapelle & Cunningham, 2007) provided evidence from both teacher and students that this integrated curriculum enhances both environmental and technological understandings.

In Technology Use and Assessment, an online course at Ball State University, graduate students collaboratively examine processes and techniques for assessing and forecasting the real and potential impacts of technology on the environment, human health, and society. The purpose of these activities is to inform policy decisions. Many environmental issues have served as the focus of these assessments, such as the following:

> [During] the fall of 2005, the contract fictitiously originated from the U.S. Senate Committee on Energy and Natural Resources and requested a well-researched technology assessment of the energy opportunities presented by American roofs. The assessment of this issue sparked inquiry into the green-house effect, energy efficiency, micro-climates, electric power grid, battery technology, housing design, rain water run-off, solid waste, photovoltaic and solar thermal technology, and green roof technology. (Rose & Flowers, 2008, p. 6)

At the high school level, students in some Virginia schools may take Technology Assessment as the final course in the Design and Technology Program sequence (Virginia Department of Education [VDOE], 2012).

The EnviroTech Project

The development of the EnviroTech project was guided by several principles, including the examination of an authentic problem with rich environmental concepts and principles, exposure to life cycle thinking, a focus upon inquiry to shape learning experiences, and a respect for the autonomy and personal agency of teachers and their students.

An Authentic Problem

The EnviroTech Project was cast against one of the most complex environmental issues of the 21st century: the interactions between the carbon and mercury cycles on planet earth and an electrical system that is powered by fossil fuels. It started with innovation. In the late 1870s, Thomas Edison and Francis Upton developed a durable incandescent light bulb that heated a carbon filament within a vacuum (Consolidated Edison, Inc., n.d.). Recognizing that the light bulb would not be a commercial success without a system to power it, Edison developed and installed the first coal-fired electric generating and distribution system to light the streets of New York City in 1882 (U.S. Energy Information Administration [EIA], 1995).

The average U.S. home contains about 40 light sockets, and lighting accounts for about 20% of the electric bill (Energy Star®, 2006). "In 2010, 45% of the Country's nearly 4 trillion kilowatt hours of electricity used coal as its source of energy" (EIA, 2011a) emitting an estimated 2.4 billion metric tons of carbon dioxide (EIA, 2011b) and 48 tons of mercury into the atmosphere (U.S. Department of Energy [DOE], 2009). Collectively switching to more efficient lamps and increasing energy-conserving behaviors should reduce carbon and mercury emissions to the atmosphere. The lighting energy efficiency standards set within the Energy Independence and Security Act of 2007 (Public Law 110-140, Subtitle B) makes significant progress in assuring that inefficient lamps, such as incandescent lamps, will be removed from the U.S. marketplace by 2014. However, the more complex issues of how to influence consumer behaviors—conserve electricity and keep mercury-containing lamps from municipal landfills—and minimize carbon and mercury emissions from power plants are far more elusive. What once were seemingly simple decisions, such as purchasing and disposing of a light bulb or flipping an electrical switch, take on global significance as people learn more about the material cycles that occur on earth.

Environmental Concepts and Principles

Material cycles, also known as biogeochemical cycles, refer to the natural occurring processes that transport, transform, and store materials through living organisms (animals and plants), the air, water, and land (Smil, 2007). Carbon quickly circulates between the biosphere and atmosphere through basic processes of photosynthesis, respiration, deposition, and combustion, but it moves on a geological time scale when forming rocks (Harrison, 2003). After millions of years, carbon, mercury, and other materials become stored in minerals, such as coal and petroleum. Burning coal releases these materials into the atmosphere.

Mercury that is released into the atmosphere eventually returns to soils and waterways primarily through a process of wet deposition (U.S. Environmental Protection Agency [EPA], 2007). Microorganisms in soils and water consume this mercury and transform it into methylmercury, a neurotoxin. Larger organisms ingest the smaller ones, and eventually the mercury moves up the food chain and bioaccumulates in top predators, including fish, loons, mink, otter, and killer whales. In large doses, exposure to methylmercury can cause "death, reduced reproductive success, impaired growth and development, and behavioral abnormalities" (EPA, 2007, p. 0-3). People are exposed to mercury by consuming contaminated fish or breathing mercury vapors. Exposure can result in brain and nervous system impairment, especially to a developing fetus, infants, and children (Agency for Toxic Substances and Disease Registry [ATSDR], 1999).

The material cycle may be imbalanced by increasing the rate at which these materials move from storage sinks to being in flux. Combusting coal at electrical power plants increases the rate and volume of carbon dioxide (0.0007 Mt/kWh, EPA, 2011) and mercury (0.012 mg/kWh, Energy Star®, 2010) that is emitted into the atmosphere. Increased concentrations of carbon dioxide in the atmosphere trap the thermal energy emitted by the earth and contribute to the rise in surface temperature (National Aeronautics and Space Administration [NASA], 2012), to the acidification of the ocean (U.S. National Oceanic and Atmospheric Administration [NOAA], n.d.), and to changes in our global climate.

Life Cycle Thinking and Inquiry

During a school semester, 19 EnviroTech teachers, guest speakers, and project staff interacted in five synchronous online webinars to build their understanding of environmental processes, inquiry, and technology assessment. All learning experiences were guided by two essential questions that established a connection between a personal decision and an authentic environmental problem:

- How might replacing incandescent lamps with compact fluorescent lamps (CFL) impact the environment and society?
- What strategies might individuals and communities use to reduce the negative impacts of replacing incandescents with CFLs? (Rose, 2010, p. 44)

The instruction and resources provided to teachers encouraged them to adopt guided inquiry, conduct controlled experiments with lamps (Rose, 2009a), and apply life cycle assessment (LCA) as a framework for learning (Rose, 2009b). LCA involves looking both upstream and downstream at each major phase of a product's life cycle, including extraction of raw materials from the environment, design and production, packaging and distribution, use and maintenance, and disposal (Scientific Applications International Corporation, 2006). After bounding the LCA study, the first task is to take an inventory of the inputs and outputs – the energy, materials, water, solid wastes, and atmospheric emissions – of each phase of a product's life cycle. Next, the assessor seeks evidence of the human and ecological effects of these inputs and outputs and then forecasts these impacts into the future. Finally, the user interprets these results to make more informed decisions. The results of an LCA are used by legislators to better inform the development of policies and by business leaders to inform changes to products, processes, or operations. By using LCA as a framework for learning, the hope was that students would develop systemic ways of thinking about the relationships among human decisions, technology, and the environment.

Results of the EnviroTech Project

As evidenced by pretests and posttests, EnviroTech teachers improved their understanding of environmental processes, reported substantial-to-extensive gains in knowledge relative to mercury deposition and bioaccumulation, and were likely to use guided inquiry, experimentation, and life cycle assessment in the future (Rose, 2010). But, if the ultimate goal of professional development programs for teachers were to enhance student achievement (Fishman, Marx, Best, & Tal, 2003), then the value of the EnviroTech Project should be examined relative to student outcomes.

Sample and Procedure

During March and April of 2009, middle ($N = 10$) and high school ($N = 8$) teachers invited their 6th-12th grade students ($N = 380$) and their parents/guardians to participate in an evaluation study of the EnviroTech Project per an approved protocol. As a token of appreciation for participating, students and their parents were offered a $5.00 purchase card. Parents and students who elected to participate mailed the consent form directly to the university; teachers were not aware of who elected to participate.

Immediately before and after implementing the guided inquiry experience, teachers administered the same test, Impacts of Technology, to their students. The instrument assessed students' understandings of key environmental, technological, and technology assessment concepts and principles, as well as items to assess attitudes and levels of commitment to environmental stewardship. This researcher-produced instrument was validated by three external experts, including those with backgrounds in environmental education, technology assessment, and environmental assessment, and it was checked for readability by two technology teachers.

At the end of the school year, after all grades had been recorded, participating teachers mailed to the researcher the assessment forms of students for whom informed consent had been received. Of the 380 invitations distributed to students, 126 students were given parental permission to participate in the study. Of these, only 96 (25% of 380) sets of assessments were usable for matched-pair (pre and post) analyses. As indicated by Table 1, 70% of student participants were from middle school classrooms, and 65% were male.

Student Learning Activities

EnviroTech teachers customized and implemented inquiry-learning experiences with their students to address the aforementioned essential questions. A content analysis of teachers' end-of-project teaching portfolios documented the use of a variety of instructional strategies, including experimentation with lamps (68%), energy calculations (32%), life cycle assessment (25%), force field analysis (11%), and forecasting (11%). Some students conducted surveys to discover how people disposed mercury-containing lamps, others welcomed a lamp recycler and a physician as guest speakers in their classroom, and one visited a fish hatchery to emphasize the bioaccumulation of mercury in the food chain.

Student Results

Knowledge changes. Fourteen test items probed students' understandings about mercury and human health, environmental processes, technology, and technology assessment methods. A Wilcoxon signed-ranks test was employed to examine the differences between pretests and posttests for all 14 multiple-choice knowledge items (Table 2); analyses showed a statistically significant difference between pretest and posttest ($Z = -7.531$, $p < .000$). Further analyses (Table 3) revealed that the percentage of correct responses increased for 12 of 14 knowledge items. From pretest to posttest, the largest increase occurred in students' ability to identify coal-fired power stations as the largest source of mercury pollution (up 55%). There were also important gains related to human health; an additional 50% of students recognized that eating contaminated fish was the most common way that people are exposed to mercury, and an additional 33% could explain that mercury impairs the brain and nervous system. Furthermore, there were significant gains related to environmental processes with students' understandings of bioaccumulation up 34%, and deposition up 22.9 %. Students also learned important lessons about technology, including how a CFL works (up 43.7%) and how mercury is reclaimed from fluorescent tubes through a process of retorting (up 37.5%).

Two items showed a decrease in the percentage of correct responses on the posttest. The validity of these items is in question. EnviroTech instruction characterized the energy efficiency of a lamp as lighting efficacy and offered the test item responses as formulas. This characterization may have confused students regarding energy conversion efficiency (ratio of energy out to energy in) and lighting efficacy (i.e., luminance divided by electrical power). The item assessing CFLs as household hazardous waste is probably indicative of the

Table 1. Characteristics of Student Participants in the EnviroTech Evaluation Study

Level	Grade	Male (f)	Female (f)	TOTAL by Row	TOTAL by Level
High School	12	6	0	6	
	11	4	4	8	
	10	12	1	13	29
	9	1	0	1	(30%)
	Unknown Grade		1	1	
Middle School	8	17	10	28	
		Unknown sex = 1			67
	7	17	16	33	(70%)
	6	5	1	6	
TOTALS		62 (65%)	33 (34%)		96 (100%)

Table 2. Statistical Comparison of Student's Combined Pretest & Posttest Knowledge Items

	Md[1]	IQR	Wilcoxon Signed-Rank Test	Asymptotic Significance (2-tailed)
Pretest	4.6	3.73	-7.531	.001
Posttest	8.2	5.82		

[1]Calculated from grouped data.

inconsistencies in state regulations regarding the disposal of fluorescent lamps. For instance, the Massachusetts Mercury Management Act "bans the disposal of products containing mercury in trash, starting May 1, 2008" (Massachusetts Department of Environmental Protection, n.d.), whereas in most states no such laws exist; however, consumers are encouraged to take fluorescent lamps to a household waste collection point.

There was also strong evidence that students learned how to protect themselves from exposure to mercury if a fluorescent lamp breaks. Students were asked how much they agreed with the following statement: "When a fluorescent lamp breaks, immediately vacuum the area." A statistically significant difference ($Z = -4.380$, $p < .000$) was found between pretest (11% correct) and posttest (55% correct). Student responses to the following open-ended item also supported this conclusion: "Describe three actions you should take when a compact fluorescent bulb or fluorescent tube breaks." Analysis of student responses revealed that 66% (61 of 93) of students would correctly begin cleanup by airing out and vacating the room several minutes before attempting to collect broken parts.

Student attitude assessment. Test items were also included to gauge changes in students' attitudes regarding the potential impacts of technology and the criteria they used when making purchase and design decisions. Comparisons between pretests and posttests yielded two statistically significant differences: students became more keenly aware that the products they buy may impact the environment ($Z = -2.872$, $p = .004$) and the way these products are disposed of can make people sick ($Z = -3.393$, $p = .001$).

Given current initiatives to infuse engineering design into K-12 education, the cluster of six items which assessed changes in students' purchase and design criteria (Table 4) should be of interest to technology and engineering educators. All items – energy consumption; recyclability; time for material breakdown in landfills; harm to people or animals; and affect water, air, and soil – showed statistically significant improvements from pretest to posttest. In addition, students were asked to rank-order the top three traits that were the most important to them when buying a light bulb for their bedroom. As indicated in Table 5, pretest rankings placed *nontoxic* as the highest ranked trait, with *energy efficiency* in fourth position. However on the posttest, energy efficiency and nontoxic were ranked in 1st and 2nd position, respectively. This data suggests that students will consider the environmental impacts of their future actions as they make design decisions in technology laboratories and in the marketplace. It may also indicate a stronger commitment to purchase energy-efficient products and reduce purchases of toxic materials.

Table 3. Percent Comparison of Students' Pretest & Postest Knowledge Items

Knowledge Items	Pretest % Correct	Posttest % Correct	Difference	Rank
Largest source of mercury pollution in U.S.	16.7	71.9	55.2	1
How humans are exposed to mercury	16.7	66.7	50	2
How a CFL works	29.2	72.9	43.7	3
Retorting: Capture chemical in spent lamp	16.7	54.2	37.5	4
Bioaccumulation and food chain	27.1	61.5	34.4	5
Mercury impairs brain and nervous system	47.9	81.2	33.3	6
Why replace incandescents with CFLs	52.1	85.3	33.2	7
Electricity generated by burning coal	20.8	51.6	30.8	8
Mercury deposition	27.1	50.0	22.9	9
How to dispose of spent fluorescent lamp	53.1	76.0	22.9	9
Technology assessments are used to…	14.6	36.5	21.9	11
Life cycle analysis: Identifying impacts	36.5	50.0	13.5	12
Energy efficiency of a light bulb	30.2	22.1	-8.1	14
CFL is household hazardous waste	86.5	78.1	-8.4	15

Table 4. Comparison of Purchase & Design Criteria on Students' Pretests and Posttests

When you purchase or design a product, how often do you think about the following issues?	Pretest[1] Median[2]	IQR	Posttest Median	IQR	Z	p (2-tailed)
How much energy it uses?	2.4	.75	4	1.75	-2.502	.012
Whether it can be reused/recycled?	3	2	3	1.0	-3.642	.000
How quickly materials breakdown in landfill?	2	2	3	2.0	-4.043	.000
How it might harm people?	3	2	4	2.0	-4.933	.000
How it affects water, air, and soil?	3	2	4	2.0	-4.389	.000
How it affects animals?	3.5	1.75	4	2.0	-3.760	.000

[1] Responses ranged from "Always (+4), Often, Sometimes, Rarely, and Never (0)".
[2] Calculated from grouped data.

Table 5. Comparisons of Student Ranked Purchase Criteria for Light Bulbs

	Pretest Rank	Pretest Frequency	Posttest Rank	Posttest Frequency
Nontoxic	1	31	2	25
Long Life	2	21	3	16
Price	2	21	3	16
Energy Efficiency	4	16	1	35
Color & Shape	5	7	5	4
Total		96		96

Conclusion

EnviroTech, an online professional development project for teachers, aimed to improve their knowledge of environmental processes and their skills regarding guided inquiry and technology assessment. The decision of whether to replace incandescent lamps with compact fluorescents served as an authentic consumer decision around which teachers planned and implemented an inquiry-based learning experience with their students. In so doing, students examined lighting technology and the mercury cycle while learning how to use different techniques, such as experimentation and life cycle assessment, to assess the impacts that mercury has on the environment and human health.

Assessments and teaching portfolios indicate that EnviroTech teachers significantly improved their understanding of environmental processes, expanded their instructional strategies for assessing the impacts of technology, and reported strong intentions to integrate sustainability principles into their teaching (Rose, 2010). The merit of professional development for teachers, perhaps, is better judged by the impact the initiative had on student outcomes. Twenty-five percent (96 of 380) of middle and high school students impacted by the project agreed to participate in the evaluation study reported here. Given the small convenience sample, these results may not be representative of the students who were affected by the project. The diverse set of learning experiences implemented by teachers, such as experiments, life cycle assessments, surveys, and guest speakers, also limits conclusions that can be drawn regarding the inquiry strategies.

As evidenced by students' pretest and posttest assessments, knowledge gains were evident relative to environment and technology, especially in regards to identifying coal-fired power plants as the major source of mercury emissions, identifying the consumption of contaminated fish as the primary route by which people are exposed to mercury, and understanding how a CFL works, how bioaccumulation happens, and that mercury impairs brain functions. Furthermore, statistically significant changes occurred in students' attitudes. Students reported greater attention to sustainability issues when purchasing and designing products, including energy consumption, recyclability, time for material breakdown in landfills, harm to people or animals, and ways these products might affect the water, air, and soil.

There are several compelling arguments for technology and engineering teachers to strive to simultaneously enhance students' environmental and technological literacy, including the goal of helping technology and engineering students meet Standards 5 and 13 of the STL (ITEA, 2000). Assessing the impacts of technology on the environment requires advanced understanding about technology, ecosystems, and environmental processes, as well as skills to identify and forecast these impacts. Few instructional models and resources exist to help teachers address these standards, and even fewer have been tested. Curriculum developers need to select accessible environmental problems and carefully craft assessment tasks that expose students to the environmental processes of which people are a part. The EnviroTech project, with its examination of lighting decisions, coal-fired electricity generation, and the mercury cycle, provides one example of weaving together these complex issues. However, we have much to learn about how to use technology assessment tools, such as life cycle assessment, forecasting, and force field analysis, and how to infuse sustainability principles into technology and engineering instruction. We need research-based evidence about the learning processes students use to assess the impact of technology on the environment. In the face of complex environmental problems, we must learn how to facilitate a student's ability to conduct inquiry, synthesize knowledge and skills from a variety of subject areas, and make informed decisions that lead to environmentally sustainable actions.

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