# Using Geographic Information Systems to Support Student Learning through Urban Ecology

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**Abstract**: This paper describes our urban street tree curriculum project in which we engage students in an ecological and economic evaluation of trees in highly populated areas through the use of Geographic Information Systems and modeling technologies. In particular, students conduct a tree inventory of the grounds surrounding their school and then use an urban tree modeling extension in ArcView called CITYGreen to evaluate the value of their neighborhood trees. Using these technological tools students are able to ask "what if" scenarios and evaluate the impact of redesigning the green space around their school. Using a mixed method approach we have found that students show significant increases in learning outcomes and express considerable interest in becoming caretakers for their urban environment.

## Introduction and Purpose

Today many students are immersed in a culture of video games, cell phones, podcasting, blogging, instant messaging and other kinds of media-intensive experiences. This rapid emergence of the current media culture in which students have access to information technology tools has democratized how youth participate in the world . For instance, according to Henry Jenkins who directs the MIT media literacy program argues that youth are no longer spectators, or even consumers of information rather they are active participants in contributing and shaping information through the use of information technology tools and resources (Jenkins, 2006). As a result, students are immersed in a cultural context that is often at odds with typical classroom experience. Namely, in classrooms students are expected to be consumers, rather than producers of knowledge. On top of this rapid shift has been a shift in the nature of knowledge. Further, as argued by Duguid and Brown (2004) knowledge is understanding how to search, evaluate, organize and use information in order to learn, problem-solve, make decisions -in formal and informal learning contexts, at work, at home and in educational settings. Unfortunately, today too many students are leaving are not equipped with either the technological or analysis skills to examine information, ask questions, indentify patterns, and be able to explain the meanings behind the patterns discerned through a critical analysis (National Research Council, 2006). This gap is most prominent when one discusses students from underrepresented backgrounds in science and technology fields. Research on the use of information technology in classrooms reveals that students in high poverty urban areas are consistently falling behind their peers (National Telecommunications and Information Administration, 2000). For example, a national study by Becker (2000) documented that students in low income areas often use technologies for repetitive activities, whereas students in higher-income areas often use technologies for higher-order thinking, problem solving, and other intellectually challenging activities (Ladson-Billings, 1997; Pollard, 1993). Further, information technology is often used independently of content in urban classrooms, which limits the understanding that students, and in turn the meanings that they can develop regarding the use of information technologies (Songer, Lee, & Kam, 2002). With the above concerns our project team has been developing, through support from the National Science Foundation, a Geographic Information System technology-enhanced curriculum project to support urban students in learning about the impacts of urban forests on their city's climate, environment, energy use and how those factors impact climate change. It is the focus of this paper to describe the program and how participation in the program has impacted student learning outcomes.

## Background

### Theoretical Framework

This study and the design of our project is grounded in a theoretical framework of learning referred to as situated cognition (Brown, 1989; Cobb & Bowers, 1999; Cognition and Technology Group at Vanderbilt, 1993). From a situated cognition perspective learning and action are not separate constructs, but rather learning, action, and context are deeply intertwined with one another. In short, learning is mediated and shaped by the context, social interactions, and tools such as community resources that constitute a particular learning environment. From a situated learning perspective if students are to develop rich, meaningful and useable understandings of scientific phenomena as well as the process of scientific knowledge construction, they need to be engaged in a scientific community of practice in which they are *doing* science in a real world setting not simply reading about science (Barab, Hay, Barnett, & Keating, 2000; Lave & Wenger, 1991). From this perspective the urban environment, specifically urban ecosystems, have significant potential to become learning resources that teachers can leverage to engage students in the study of phenomena that is both locally relevant and has a direct impact upon their daily lives (Bouillion & Gomez, 2001).

Previous research has highlighted that access to resources, though important, is only part of the story (Spillane, Diamond, Walker, Halverson, & Jita, 2001). Spillane and colleagues (2001) point out that the impact of resources on student achievement requires extending our vision of resources beyond the school and classroom to include the entire school community. In addition, it is not sufficient to simply identify the resources, but to understand how to use, or *activate* these resources to ensure that they are usable by students. Historically, the resources that schools have used to teach science are the classroom, laboratory, and the outdoors (Orion & Hofstein, 1994). Unfortunately, the outdoor environment is the one most neglected by teachers, curriculum developers, and researchers (e.g., Orion & Hofstein, 1994). Researchers have also found that teachers tended to avoid outdoor activities because they were frequently unfamiliar with the philosophy, technique, and organization of field trips (Fido & Gayford, 1982). In other words, the teachers did not have the requisite skills, knowledge or confidence to *activate* the urban outdoor environment as a learning resource. Hence, our work has focused on designing and researching projects that support teachers and students in activating the urban environment, with the support of information technologies, as a learning resource for their students.

### Urban Environmental Science Education and Information Technologies

Urbanization trends of the past century show a dramatic rise in the size of cities. Over 300 cities have more than 1 million inhabitants, and 16 "megacities" have populations exceeding 10 million. In light of such population pressures, urban natural resources, such as urban watersheds, forests, and wildlife are critical to maintaining cities and to providing economic, civic, and public health benefits for metropolitan area residents worldwide (Grimm, Grove, Pickett, & Redman, 2000). At the forefront of ensuring that urban ecosystems maintained are young people who are and will be living in cities. Unfortunately, all too often students in cities are not provided with the training they need to understand or appreciate the ecological richness of their city, nor do they have the scientific skills to understand how their actions impact their urban ecosystem, how they can improve and change their city's ecosystem for the better, and how a healthy urban ecosystem impacts their own lives (Manzanal, Barreiro, & Jimenez, 1999). In fact, to date teaching of ecology in high school classrooms has primarily focused on the study of areas where there has been relatively minimal human intervention. For example, in their 2004 review of environmental science high school textbooks, the Environmental Literacy Council (2004) found that very few books critically examined urban ecosystems, the impact of cities on the environment, and the role that humans have had in creating, changing, and impacting urban ecosystems. Thus, it is not surprising that there have been few research studies that have examined student beliefs and understanding of urban ecosystems as documented by Rickinson's (2001) extensive review of the empirical environmental education research literature.

Geospatial technologies such as Geographic Information Systems (GIS) have emerged over the last fifteen years as one of the key tools used by environmental scientists (National Research Council, 2006). However, a disconnect exists between the research conducted by professional environmental scientists and how environmental science is taught in typical public school classrooms. Few students work with tools regularly used by scientists or pursue authentic inquiries using current scientific data, regional or global information, and available research tools (National Research Council, 2006). However, recently there has been a dramatic increase in the availability of user-friendly geospatial technologies for educators (such as MyWorld, Google Earth, and ArcExplorer) have increased the potential for use of Geographic Information Systems (GIS) technologies in schools. During the previous two years our project team has been developing curriculum materials for use in urban schools that leverage ArcView, the premiere GIS software package and CITYGreen which is an extension for ArcView which allows students to evaluate the economic and ecological value of urban street trees.

## Study Context

### Curriculum Project Description

Our urban tree project capitalizes upon the increased recognition that city street trees have significant positive ecological impacts (McPherson et al., 1997). The urban street tree inventory is conducted using GIS technologies and CITYgreen, a software package develop by American Forests that plugs into the Geographical Information Systems software package, ArcView. CITYgreen allows students, through the use and labeling of satellite images, to link each tree location to a database of geographic, classification, and health information and to conduct analyses regarding the economic and ecological benefits of urban trees. http://www.americanforests.org/productsandpubs/citygreen/ for a description of CITYgreen).

In this project students collect data on tree location and condition in the field and then and use CITYgreen to evaluate the economic value of street trees on such constructs as storm water runoff, energy savings, and air pollution removal. The students also evaluate the impact of street trees on air quality and the rate of carbon sequestration and determine how much carbon is stored in their urban street tree sample. However, what is perhaps most powerful about this project is that once students have collected their data (or used data from an existing street inventory for their neighborhood) and conducted an initial baseline data analysis, they can then ask “what if” questions.  For example, in the city of Boston there has been significant news coverage of the “Big Dig” where the city has diverted the major interstates that were running through city into underground tunnels and currently in the process of converting the reclaimed land into green space. Further, a number of cities in the United States are currently undertaking massive tree campaigns to increase the tree canopy of their city.  In particular, the city of Boston will be planting 100,000 trees in the next ten years to increase the city’s tree canopy from 26% to 35%. Thus, through the use of the ArcView and CITYGreen students are able to write a letter to the mayor of the city and request that trees be planted in particular areas and be able to justify their reasoning with a dollar figure. As a result, students can quickly generate findings that are not only relevant to themselves, but they can also generate knowledge that is useful to policy makers and the general public (See Figure 1 and 2 for images of student work).

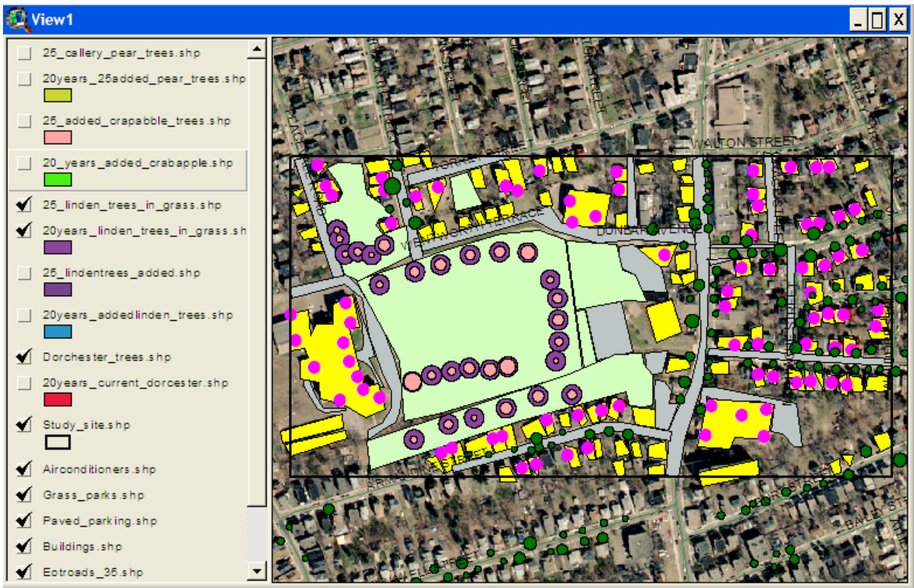


Figure 1.  Students’ GIS map of planting trees around their school in grassy areas and then evaluating their ecological and economic impact in 20 years. Students are able to “re-draw” their urban neighborhood and evaluate the impact of their tree planting locations on the environment. Note that in this project students have several layers (left side of the image) in which they have tested and evaluated various scenarios including whether Linden, Pear, or Crabapple trees are best to plant and they have also investigated where would be good locations plant the trees.

**Ecological Benefits**

**Air Pollution Removal**

Air Quality Reference City: Boston

| | lbs Removed | Dollar Value |
|---|---|---|
| Ozone: | 40 | $123 |
| Sulfur Dioxide: | 11 | $8 |
| Nitrogen Dioxide: | 25 | $77 |
| Particulate Matter: | 30 | $62 |
| Carbon Monoxide: | 4 | $2 |
| **Total:** | **110** | **$272** |

**Residential Cooling Effects**

| | | |
|---|---|---|
| Average Annual Cooling Cost per Home: | | $600.00 |
| Number of Homes: | 122 | |
| Savings from Trees: | | $3,068.88 |
| Savings from Roofs: | | $0.00 |
| **Total Savings:** | | **$3,068.88** |
| Savings per Home: | | $25.15 |
| Kilowatt-hours Saved: | 31,637.94 | |
| KWHs Saved per Home: | 259.33 | |
| Carbon Generation Avoided: | 1,264,343.76 lbs. | |
| Carbon Generation Avoided per Home: | 10,363.47 lbs. | |

**Carbon Storage and Sequestration**

| | | |
|---|---|---|
| Age Distribution of Trees: | | Mature |
| Carbon Storage: | 56 | tons |
| Carbon Sequestration: | 200 | pounds/year |

**Stormwater Control**

Average 2-yr, 24-hour Rainfall: 3.50 in.

| | Conditions: Current | w/o trees* | |
|---|---|---|---|
| Curve Number: | 76.00 | 79.00 | |
| Runoff (in.): | 1.37 | 1.57 | |
| Storage volume needed to mitigate the change in peak flow: | 3,581.97 | | cu. ft. |
| Construction cost: | $2.00 | | per cu. ft. |
| **Total** | **$7,163.94** | | |

*Replaced by default landcover: Urban: Residential: 0.5ac Lots

Figure 2. A student generated report. This figure shows the impact of planting 25 trees and their ecological and economic impact on the neighborhood in 20 years. Students are expected to understand the science and be able to interpret the above report. Then, using this report student can then justify or argue against planting trees in particular locations in their neighborhood.

### Sample

Our research has taken place in two major locations. First we have implemented our project in four inner city high schools (N = 215) whose population is mostly (94%) from students who are considered to be from underrepresented populations in science. We have also conducted our research in an urban-suburban high school (N=385) whose population was quite mixed with 40% white, 30% Hispanic, 15% African-American, 10% Asian, and 5% a mixture of other cultures). The last location was an affluent suburban schools who population was predominately Caucasian (N=70, 88% Caucasian, 10% Asian-American, 2% other).

## Research Questions and Methods

Our research and development agenda has been consistent with Brown's (1992) notion of "design experiments", (design experiments have been refined to and now referred to as designed-based research (DBR)) in which entire instructional interventions are designed (as opposed to constrained laboratory contexts) and the impact of innovations on the learning and teaching process are examined. The lessons learned are then cycled back into the next instructional intervention, where we can examine the impact on our teaching and our students' learning.

Design-based research (DBR) is ideal for mixed-methods studies, and accommodates some of the strengths and weaknesses of qualitative and quantitative approaches to education research. DBR is generally situated within qualitative methodologies of description, but explicitly studies a theoretically informed intervention (in our case a situative designed elementary science methods course) within the messy context of a real-world setting. DBR is iterative; research findings derived *in situ* are used to refine the original theories that helped construct the intervention, and it is understood that the intervention will be strategically amended as the research progresses to better accommodate amended theoretical understandings. That is, based upon our research findings we have been continuously revising and refining the structure of our elementary science methods courses.

DBR is an ideal research framework for our work as it serves both the local needs of informing our course design and fills in the gaps in the global research knowledge base. Locally, our findings will be used to inform the redesign of our methods course. At the global level, given that every teacher education program engages students in an elementary science methods course, we hope that our findings will provide guidance to other teacher educators regarding the use of authentic contexts and engaging pre-service teachers in the evaluation and implementation of reform-based curriculum as a core aspect of an elementary science methods course.

We have been conducting design experiments in which we have been researching how our interventions play out in the complex and messy world of classrooms and use the results of research to redesign our materials. To that end the driving questions for our work have been:

1. What are the challenges that teachers and students experience while attempting to implement the project?
2. How does participation in the project improve student learning outcomes?
3. What are the barriers to implementation of the project in the classroom?
4. What are teacher and students perceptions of the technological tools?

## Data Collection and Analysis

A mixed methodological strategy was used for data collection in this research (Tashakkori & Teddlie, 1998). We administered a pre-post content exam that consisted of multiple choice items that were derived from standardized exam questions and open ended questions. We also randomly selected a subset of students (N=30) and administered a pre-post semi-structured content interview in which we explored students' depth of understanding, their knowledge of GIS and their perceptions of their urban environment. We also conducted classroom observations and teacher interviews to better understand the type and nature of the questions that the students asked and to evaluate the challenges that teachers experienced while implemented a GIS based project.

Data analysis consisted of conducting a paired t-test analysis on the students' content exam and the development of rubric for the students' open ended questions and interview responses. We also conducted ANOVA and ANCOVA analysis to evaluate any gender and race effects and overall project effects. The content exam reliability was found to be .75 and we have not conducted an inter-rater reliability analysis of the rubric analysis as of this writing. We assessed student understanding as measured by the interviews by listening to the audio recordings of the interviews and scoring the student responses by a rubric. The rubric is based upon the categorization scheme used by a number of researchers (e.g. Keating, Barnett, Barab, & Hay, 2002). Both the pre and post-interview responses were scored using a rubric adapted to the question of interest. In evaluating the open ended student responses and the student interviews we developed a rubric and scored each question. Lastly, using a grounded-theory approach to examine our field notes we indentified and searched for confirming and disconfirming evidence regarding teacher and student challenges in implementing and completing the project (again for the purposes of this proposal we will focus on the student outcomes).

## Findings and Discussion

For the purposes of this paper we are focusing our attention on student outcomes. We have found that students who participate in the project show significant growth in terms of their content understanding ($t_{pre}$ = 2.5, $p < 0.01$, $t_{post}$ = 3.4, $p<0.01$) for urban students and ($t_{pre}$ = 3.1, $p < 0.01$, $t_{post}$ = 3.6, $p<0.01$) for the urban/suburban students). In evaluating the difference on urban as compared to suburban students we found significant difference between students from under-represented backgrounds in science regardless of location we found a significant difference, $F(2, 660)=6.0$, $p<.01$) with students of color improving their performance on the content exam ($M_{pre\_urban}$ = 5.5, $M_{post\_urban}$ = 8.0) as compared to the Caucasian students ($M_{pre\_urban}$ = 7.5, $M_{post\_urban}$ = 9.8). Further, to evaluate the overall impact of the project on student outcomes we conducted an analysis of covariance with the pre-test as being the covariate and found that all students showed a significant increase in their content understanding regarding the functioning and process of urban trees, $F(2,669) = 5.5$, $p<.01$).

We also found similar results for the interview and open-ended responses as we did for the content exam ($t_{pre\_all}$ = 2.0, $p < 0.01$, $t_{post\_all}$ = 3.2, $p<0.01$). However, through our analysis of the interviews we found that at the beginning of the projects nearly all students, but particularly, urban students did not recognize that urban trees had value beyond removing carbon dioxide from atmosphere and adding oxygen to the atmosphere. For example, the following interview exchange was typical:

| | |
|---|---|
| Interviewer: | So what do you think is the most important contribution of trees to the environment? |
| Student: | Well, it would have to be that they give us oxygen and take out carbon dioxide. |
| Interviewer: | Where did you learn that? |
| Student: | I don't know. Middle school? Just have heard it for a long time. |
| Interviewer: | Why is taking carbon dioxide out of the atmosphere important? |
| Student: | Well, it is important because of global warming. Carbon dioxide is important because it is causing the planet to warm up. |
| Interviewer: | Anything else that trees add to the environment? |
| Student: | Hmm. Not that I know about. Oh, I guess that help make the city cleaner. |
| Interviewer: | How do they make the city cleaner? |
| Student: | I guess they clean the air? Oh, they also make the city look nicer. |

However, as the project progressed students began to recognize that urban trees are considerably more valuable than they had previously thought. This shift in perception is represented in the following excerpt from a student presentation in which a group of students were articulating why they were suggesting particular locations to plant trees:

> Our research question was: "What would be the impact of planting 25 Norway maple trees around our school. We found that by planting the trees on the south side of the building provided the most energy savings for the school and also provided the best way to slow global warming because by planting them there 555,000 lbs of $CO_2$ would not be produced by the school because the building wouldn't need to be air conditioned as much. We found Maple trees would be the best of any tree species we tried because they also absorbed the most pollution. We believe this to be the case because they tend to be bigger trees and have larger leaves and as a result have more surface area on which to absorb pollution as you can see here on the reports [points to the CITYGreen reports that on the screen].

The above quote shows that the students are generating results that are based upon their own research questions and that students' are generating scientific arguments based upon their own findings and using those finds to make recommendations that can have a significant environmental impact in an area where they live.

Another important finding is that the students could articulate the importance of urban trees compared to trees in other areas as noted by the following student interview:

| | |
|---|---|
| Interviewer: | Tell me about your research question. |
| Student: | We investigated whether planting Linden trees on the streets that did not have trees would have more or less impact than trees planted around the school. |
| Interviewer: | What did you find? |

Student: We found that the trees near the school were better.
Interviewer: Why?
Student: They were better because they could shade the building which reduce energy costs and keeps the parking area cooler which reduces energy costs and they also absorbed more pollution. They are more valuable too because they also prevent more carbon dioxide from entering atmosphere than the trees far away from the building because of the energy use.

In analysis of the opened response items we also found that students' increased the complexity and scientific accuracy of their responses. In the pre-tests most students described that urban trees were important for cleaning the air, removing CO2, and making the city a more comfortable and aesthetically pleasing place to live. However, in the post interviews students increased the complexity of their responses and also used evidence collected during their investigations to defend and justify their responses. This shift is exemplified by the following typical student pre-post open ended response:

Student Pre: An increase in Boston's tree canopy would bring many benefits. First, it would clean up Boston's air. Second, it would help our problem with global warming by removing CO2 from the atmosphere, as well as helping the city's aesthetics. That is how an increase in Boston's tree canopy percentile would benefit Boston. In terms of where to plant trees I would probably plant them in areas that don't have any trees.

Student Post: There are many potential benefits of increasing the tree canopy in Boston. One of the ways it would help the citizens of Boston is through reduction of heat. Trees provide shade and by shading the city they help regulate the amount of heat that Boston absorbs. Another way a larger tree canopy would be beneficial is through cleaner air. The trees take out both CO2 and other pollution like Ozone which is very bad for one's health particularly those with respiratory conditions. I would plant my trees near homes because the home is a main source of greenhouse gas emissions. Thus by planting trees near homes they will provide shade and help reduce electricity costs which then will reduce the amount of CO2 from going into the atmosphere due to energy production. Trees near homes will also provide energy savings in the winter because they will block the wind and keep the homes warmer.

In comparing and contrasting the above response it is evident that the student had developed a significantly richer understanding of the complex relationships that exist between urban street trees and their ecological impact on the city.

We have also indentified three themes that cut across the study sample through our analysis of the interviews and classroom observations.

1. Students enter the project with a number of misconceptions regarding the role of urban street trees. In particular, students often believe that the Ozone layer depletion has a strong effect on global warming and that trees' primary role in slowing global warming is due to their ability to sequester carbon from the air, however, through the project students come to recognize that urban tree carbon sequestration is trivial compared to the ability of trees to prevent carbon dioxide from entering the atmosphere.
2. Students leave the project understanding what ecological changes would benefit their school or neighborhood yet struggle to articulate how they would increase their societal participation to implement those changes
3. Generally, students quickly learned the software and found the project to be more interesting than their traditional school work because it engaged them in a topic that they never thought about before, or as one student stated in an interview: "I had no idea that such things existed before or that I could use them and figure out that a tree in front of my school was worth something."

## Implications

There is compelling evidence that humans are altering the Earth's ecosystems. In fact, humans are creating new ecosystems specifically for dwelling: these are urban ecosystems (Alberti et al., 2003). However, to date the teaching of ecology in high school classrooms has primarily focused on the study of areas where there has been relatively minimal human intervention. For example, in their 2004 review of environmental science high school textbooks, the Environmental Literacy Council (2004) found that very few books critically examined urban ecosystems, the impact of cities on the environment, and the role that humans have had in creating urban ecosystems. Our work has focused on engaging those populations in critically examining their urban ecosystem.

Urbanization trends of the past century show a dramatic rise in the size of cities. Over 300 cities have more than 1 million inhabitants, and 16 "megacities" have populations exceeding 10 million. In light of such population pressures, urban natural resources, such as urban watersheds, forests, and wildlife are critical to maintaining cities and to providing economic, civic, and public health benefits for metropolitan area residents worldwide (Grimm et al., 2000). At the forefront of ensuring that urban ecosystems maintained are young people who are and will be living in cities. Unfortunately, all too often students in cities are not provided with the training they need to understand or appreciate the ecological richness of their city, nor do they have the scientific skills to understand how their actions impact their urban ecosystem (Manzanal et al., 1999). To facilitate high school student understanding of and engagement with their urban ecosystems we have found that engaging students in uing GIS coupled with computer modeling technologies within an urban ecological framework can improve their understanding of the value of their urban ecosystem.

Lastly, to date there have been few research studies that examine students' use of GIS technologies and students understanding of the impact of urban ecosystems on their environment. In fact, one of the outstanding questions put forth by the National Resource Council (2006) is: "How might current versions of GIS (geographic information system) be incorporated into existing standards-based instruction?" The work described here addresses both of these issues and suggests that GIS technology coupled with exploration of an urban ecosystem can provide students with in-depth knowledge of how the value of their urban ecosystem.

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## Acknowledgements

This work is supported in part through a National Science Foundation Information Technology Experiences for Students and Teachers (ITEST) program (Grant # 0525040); Hewlett Packard Foundation – Teaching with Technology Program (Grant# 189660).