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AUGMENTED BY REALITY: THE PEDAGOGICAL PRAXIS OF URBAN PLANNING AS A PATHWAY TO ECOLOGICAL THINKING*

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ABSTRACT

In this article, we present a study focused on developing students' understanding the ecology through participation in a technology-supported urban planning simulation—specifically, 11 high school students in Madison, Wisconsin acted as urban planners to redesign a local shopping street using a Geographic Information System (GIS) model. This experimental design was situated within the theory of pedagogical praxis, which suggests that modeling learning environments on authentic professional practices enables youth to develop a deeper understanding of important domains of inquiry (Shaffer, 2004). Results presented here suggest that through participation in the project students: a) developed an understanding of ecology; and b) developed this understanding through the urban planning practices and the features of the GIS model used during the project. Thus, we propose that this *augmented by reality* learning environment modeled on the professional practices of urban planners extends the theory of pedagogical praxis into the domain of ecology and offers a useful method for developing ecological understanding through participation in simulations that incorporate the authentic tools and practices of urban planning.

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INTRODUCTION

"Before the city, there was the land." So begins William Cronon's (1991) book *Nature's Metropolis*, an environmental and economic history of Chicago and the Great West. Cronon argues that the city and the land upon which it is built are inherently related: human beings are the architects and planners of cities, so good stewardship and good citizenship require an understanding of the interdependent relationships between both built *and natural* environments.

The environmental dependencies inherent in cities have the potential to become a fruitful context for new and innovative learning environments in ecological education. Ecology is, of course, a much broader domain than the study of interdependent urban relationships. However, cities are examples of complex systems that students can both view and experience, thus making concepts in the domain of ecology more tangible and relevant. Cities are places where students can experience how they are personally connected to an ecosystem that is directly affected by their actions.

One way students can gain an awareness of a city's ecological relationships is through urban simulation: for example, in computer games such as SimCity, where players solve urban problems by maintaining or improving interdependent relationships in a fictitious urban environment (Maxis, 2003). Such simulations model the city as a complex system, providing students with an opportunity to manipulate variables within the system and observe the consequences of their actions (Starr, 1994). The interactions in these simulated worlds provide a context for understanding cities and their ecological complexity.

Here we argue that before there was SimCity, there were real cities—and thus the epistemology and practices of urban planning may provide an authentic medium for understanding the complex relationships of urban ecology. In what follows, we present an analysis of a learning environment that asks students to solve a complex urban problem through the use of a virtual model of their own city.

This work is situated within the theory of pedagogical praxis, which claims that new technologies provide a bridge to assist students in gaining access to professional practices (Shaffer, 2004). Briefly, the theory of pedagogical praxis suggests that authentic representations of professional practices are a useful framework for designing technology-supported learning environments. We thus hypothesize that an urban planning simulation using new technology informed by real-world urban planning practices and tools may be a productive platform for developing students' understanding of the ecological domain.

To test these conjectures, we developed the Madison 2200 project: a learning environment in which 11 students had an opportunity to learn concepts in ecology by participating in a simulation activity modeled on the professional practices of urban planners. In this article, we analyze the ecological thinking of the participants in Madison 2200 by asking two research questions:

1. Did participants develop an understanding of the domain of ecology through participation in a simulation modeled on the real world tools and practices of urban planners?
2. If so, what role did the tools and practices of urban planning play in the development of this ecological understanding?

The analysis that follows uses statistical techniques and a traditional pre-test/post-test design. However, we want to emphasize that our account is fundamentally qualitative in nature. We seek to explain the experience of a particular set of students in this particular learning environment modeled on the tools and practices of urban planning. Given the small sample size means we claim only that our conclusions reflect the lived experience of the participants with whom we worked. In this mixed method approach, the role of quantitative techniques is only to warrant theoretical saturation for claims that are based on qualitative analysis (see Shaffer & Serlin).

We situate this study relative to previous research on simulations that develop ecological understanding, including SimCity and *augmented reality* learning environments (Klopfer & Squire, in press). We then describe the methods and results of Madison 2200, examining whether and how participation in a complex urban planning simulation in the context of real world tools and practices informed student understanding of ecology. Our analysis focuses on: a) the properties of the technology that make complex relationships visible and accessible to students; and b) the role that authentic urban planning practices play in the development of students' ecological understanding. We conclude with a discussion of the implications of this research for the theory of pedagogical praxis, and more generally for the development of learning environments based on ecological simulations supported by authentic urban planning practices.

THEORETICAL FRAMEWORK

Cities are comprised of simple components; however, interactions among those components create dynamic patterns of movement that lead to high levels of complexity (Allen, 1996). This complexity is represented, for example, by relationships among traffic jams, road construction, and summer vacationers, or industrial sites, air pollution, and land property values. Altering one variable within the system affects all the others, reflecting the interdependent, ecological relationships present in the modern city. A number of approaches currently exist that attempt to model this urban complexity for students.

Urban Simulations

Gaming environments such as SimCity (Maxis, 2003) are one means by which students can experience complex urban relationships. SimCity is a simulation that models complex urban systems (Starr, 1994). The simplified game rules enable students to quickly grasp and control the program. As a result, players can start acting upon the virtual environment almost immediately. Although there are significant differences in interface, content, and learning theory among SimCity and other environmental simulations such as Stella™ (Chalupsky & MacGregor, 1999) and StarLogo™ (Resnick, 1994), SimCity does exemplify the basic premise of simulation-based learning environments: students develop understanding of ecological issues by directly manipulating a model of a complex system.

In SimCity, game players take command of an urban grid and must "run" the city by maintaining a balance between several elements: a growing population, environmental perturbations, urban and economic development, and multiple social issues including crime and transportation. They can simultaneously play the role of mayor, urban planner, and city government official. The simulation exposes the complexities of urban ecology, or more specifically, what happens when a player tries to affect change in an urban ecosystem. For example, if a player increases green space in the city, the cost of public utilities also increases, or if he/she places an industrial site next to a residential one, the residential land values fall and the crime rate rises (Eiser, 1991). As a result, a player must decide to either decrease the green space and move the industry, or risk urban flight. SimCity makes visible how human choices affect environmental outcomes, and in turn, enables players to view how those same outcomes subsequently inform human choice. Previous studies have shown that SimCity can help students understand concepts in the domain of urban geography (Adams, 1998) and community planning issues in social studies curricula (Teague & Teague, 1995).

While urban simulation games such as SimCity can help students gain intellectual access to complex ecological systems, there are also significant limitations in using such tools to develop ecological thinking. In SimCity, for example, the city that a player creates and maintains does not always represent an actual city. As in StarLogo and Stella, modeled behaviors may represent realistic patterns of great complexity, but there is little possibility for actual physical experience of the city complexity being modeled. Further, there is no context (such as a planning or city council meeting) in which players explain and justify their actions—their purpose for placing industrial sites adjacent to residential ones, or funding road construction instead of the development of greenspace. As Sanger (1997) suggests, fostering a connection to local issues provides students with a voice that shapes their place within the community—a connection that may be lost in SimCity's relative lack of grounding in the authentic structures, issues, and activities of students' lives.

The expansion of space and compression of time in SimCity may also be problematic for the development of ecological understanding. In SimCity, changes occur on a wide-ranging geographical scale, presenting a macro-level view of how cities function. SimCity presents players with an entire city to manage, and directs then to pay attention to the numerous interdependent relationships that affect that city as a whole rather than understanding the more local relationships that they may experience more directly in their day-to-day lives. Real cities grow and change slowly, but to make game play interesting and enjoyable, games such as SimCity let players build new land use developments and solve urban problems on a compressed time scale. Previous research has suggested however, that complex ecological and ecosocial processes exhibit fundamentally different patterns at different timescales (Latour, 1983; Lemke, 2000). Thus, the fast-paced changes in SimCity may actually weaken understanding of how ecological problems occur in the real world—problems that typically unfold over the course of months and years, rather than the virtually accelerated time depicted in SimCity.

Augmented Reality Learning Environments

One approach to creating stronger connections between students' experience of the real world and students' actions in a virtual model of a complex ecological system is to link real and virtual elements in *augmented reality* learning environments for ecological education (Klopfer & Squire, in press). In these environments, participants are exposed to both a physical and virtual reality, thus providing students with multiple representations for constructing solutions and engaging in actions that solve complex ecological problems. While virtual reality attempts to replace the real world, augmented reality seeks only to supplement it (Feiner, 2002). Innovations in handheld, mobile technologies such as the Global Positioning System (GPS) and the Pocket PC are becoming more common in ecological education. A GPS, for example, enables a student to both gather and respond to data while maneuvering through an outdoor environment and then store it for further analysis (Broda & Baxter, 2003). Learning environments afforded by such technologies are referred to as augmented reality environments because the real world that students explore is supplemented by a related virtual component that is sensitive to changing real world information (Klopfer & Squire, in press). Augmented reality learning environments enable students to take the technology out of their classrooms and use it to explore the environment around them.

Klopfer and Squire (2004) argue that learning environments designed with augmented reality technologies enable students to participate in the process of scientific investigation because they provide students with the opportunity to develop sampling strategies, analyze data, read and interpret scientific texts to understand problems and design potential solutions. For example, the game *Environmental Detectives* is an augmented reality simulation where students are introduced to topics in environmental science (Klopfer & Squire, in press). In one *Environmental Detectives* study, students were prompted with a simulation of an environmental disaster on their hand-held technology as they explored a local watershed (Klopfer & Squire, 2004). While they traversed the area, they collected and analyzed simulated data to solve the problem. Klopfer & Squire

(2004) showed that as students acted to solve the problem, they developed both scientific and ecological understanding.

Augmented by Reality

The study presented here builds on such augmented reality learning environments. However, in this study, the learning environment is *augmented by reality*: as students engage with a virtual simulation, their problem solving experiences are explicitly guided by real-world tools and practices. Using their own city as an ecological environment, the Madison 2200 project engaged students in a learning environment modeled on the professional practices of urban planners. As in SimCity, participants made land use decisions and considered the complexities that surfaced as a result; however, here they used real-world data and authentic planning practices to inform those decisions. This experimental design was thus situated within the theory of *pedagogical praxis*, which suggests that modeling learning environments on authentic professional practices enables youth to develop a deeper understanding of important domains of inquiry (Shaffer, 2004).

The Theory of Pedagogical Praxis

The theory of pedagogical praxis suggests that new technologies make it possible for students to learn and participate in meaningful activity by serving as a bridge between professional practices and the needs and abilities of young students (Shaffer, 2004). In other words, new technologies make professional practices accessible to students. To be successful, learning environments based on pedagogical praxis depend upon the alignment of authentic professional practice, technological tool, and domain of knowledge. This study examines this conjecture by mapping it to the professional practices of urban planning, the use of a specialized geographic information system, and the domain of ecology.

The Professional Practices of Urban Planners

Urban planners engage in a variety of practices that promote urban development. According to the American Planning Association (2003), these practices include:

1. Formulating plans and policies to meet the social, economic, and physical needs of communities, and developing the strategies to make these plans work.
2. Developing plans for land use patterns, housing needs, parks and recreation opportunities, highways and transportation systems, economic development, and other aspects of the future.
3. Working with the public to develop a vision of the future and to build on that vision.

4. Analyzing problems, visualizing futures, comparing alternatives, and describing implications, so that public officials and citizens can make knowledgeable choices.
5. Designing and managing the planning process itself, in order to involve interest groups, citizens, and public officials in stimulating and thought-provoking ways.
6. Being technically competent and creative, showing both hardheaded pragmatism and an ability to envision alternatives to the physical and social environments in which we live.

In short, urban planners take a central role in trying to keep urban ecological systems in balance. They respond to complex urban problems by developing land use plans that function to simultaneously accommodate human needs and ease the burden on the places people use.

Previous research on youth involvement in urban planning programs suggests that involvement in local planning initiatives is an empowering experience, one that can lead to ecological competence and community action (Chawla & Heft, 2002; Horelli, 1997, 2001; Horelli & Kaaja, 2002; Simpson, 1997). However, this body of work emphasizes participatory urban planning efforts between children and adults rather than student engagement with computational models of urban ecological complexity, such as the models that play a significant role in the authentic practice of urban planning.

Urban Planning Technology

One of the most popular technologies used in urban planning are geographic information systems (GIS), broadly defined as a "powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world" (Burrough, 1986, p. 6). GIS models are integral to urban planning practices. Urban planners use GIS to analyze spatial information and find solutions to urban problems (Batty, 1995). GIS models have many applications, helping urban planners to ask fundamental questions about the locations of objects, how landscapes change in response to environmental conditions, or highlight patterns of emergent phenomena that become apparent over time. GIS models make it possible for planners to explore multiple potential solutions to problems, asking "what if?" questions and obtaining feedback that informs the decision making process (Maguire, 1991). In these ways, GIS models support the practices or urban planners, and thus potentially provide access to those practices for students learning about the ecology of complex urban relationships.

The Domain of Ecology

Ecology, broadly defined, is the branch of science concerned with the interdependence of organisms and the complex systems in which they co-exist. The science of ecology analyzes the connections among biotic and abiotic elements of such complex systems, describing the delicately balanced relationships upon which these systems depend and the ramifications that can occur if those relationships are disrupted. This study focused on the complex ecological systems in urban areas. A key aspect of urban ecology is that such systems directly affect and are directly affected by human activity (Alberti et al., 2003); therefore students need to understand how decisions about the urban environment—and thus *their* decisions about the urban environment—have interdependent consequences that shape the ecology of the city in which they live.

The Madison 2200 Project

The Madison 2200 project focused on developing students' understanding of this central ecological principle while they were engaged in solving an authentic urban planning problem using a GIS-based planning simulation tool. The project situated student experience at a micro level by focusing on a single street ion their city. Instead of the fast-paced action required to plan and maintain virtual urban environments such as SimCity, this study focused only on an initial planning stage, which involved the development of a land use plan for this one street. And instead of using only a technological simulation, the learning environment here was orchestrated by authentic urban planning practices. These professional practices situated the planning tool in a realistic context and provided a framework within which students constructed solutions to the problem.

METHOD

Participants

The Madison 2200 project conducted two workshops during the summer of 2003. Eleven high school seniors from a summer enrichment program on the University of Wisconsin campus spent 10 hours over 2 weekend days. The participants volunteered for a workshop focused on city planning and community service. All participants were persons of color, including eight African American, two Latino/a students and one participant of Asian descent. All participants indicated they planned on attending a post-secondary institution. Four participants were female and seven were male.

Workshop Activities

Workshops were divided into three phases: introduction, planning, and presentation.

Introduction (1 Hour)

Upon arrival at the workshop, students were presented with an urban planning challenge: to create a detailed re-design plan of State Street, a major pedestrian thoroughfare in Madison, Wisconsin and a popular downtown destination for local adolescents. A key practice of urban planners is to formulate plans that meet the social, economic, and physical needs of communities. To align with this practice, students received an informational packet addressed to city planners which contained a project directive from the mayor, a city budget plan, and letters from concerned citizens providing input as to how the street should be redesigned. The directive asked the city planners (that is, the students) to develop a plan ready for presentation to a representative from the planning department at the end of the workshop on Sunday afternoon.

Students then watched a video about State Street, featuring interviews of people who expressed concerns about the street's redevelopment that were aligned with issues in the informational packet. For example, the video featured a college student who suggested that the city should place more affordable housing on State Street; a letter from the fictitious "Concerned Citizens for Housing"[1] on the issue of affordable housing appeared in their information packets. Research to determine the current urban planning issues prior to the study; both the video and the participant information packet were created in accordance with those findings.

Planning (7 Hours)

During the planning phase, students walked to State Street and conducted a site assessment. They took pictures of buildings, and became familiar with the locations of stores and housing developments and with the various ways the street is used. Following the State Street walk, students returned to the planning space and began to work in teams to develop a land use plan using a custom-designed interactive geographic information system (GIS) called MadMod. Mad Mod is a model built using Excel and ArcMap (ESRI, 2003) that lets students assess the ramifications of proposed land use changes. MadMod has two inter-related interactive components: 1) a *decision space*; and 2) a *constraint table*. The decision space displays address and zoning information about State Street. Students used 2- or 3-letter zoning codes to designate changes in land use for property parcels on the street (see Figure 1).

As students made these decisions, they received immediate feedback about the consequences of changes in the constraint table. The constraint table showed the effects of changes on six urban planning issues raised in the original information packet and video: crime, revenue, jobs, waste, car trips, and housing. For example, if a student was interested in raising the number of jobs available on State Street, she might make the decision to place a new retail business there. The model would then show whether that proposal would raise or lower the number of jobs predicted for the neighborhood. However, the model would also show how the five other categories of revenue, crime, waste, car trips, and housing categories were affected

[1] Organizations listed in the information packet were created by the researcher.

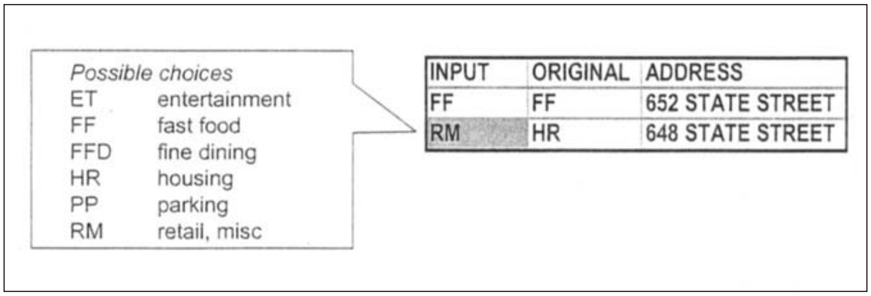

Figure 1. A piece of the *decision space* in MadMod.
Students made land use changes by placing 2- or 3-letter zoning codes in a shaded cell in the INPUT column.

by the same land use choice, thus leaving students with a decision to make regarding the overall impact (and therefore the utility) of alternative land use proposals. After completing a land use plan in MadMod, students entered their decisions into an interactive map of the State Street area (see Figure 2 for an overview of this planning process).

Presentation (2 Hours)

Following the practices of urban planners, in the final phase of the workshop students presented their plans to a representative from the city planning office. (For logistical reasons, this was actually another researcher with knowledge of urban planning practices and unknown to the students who were playing the role of a city planner). Each group of students designed a presentation that included their final interactive constraint table, the rationale for their decision-making process, and their newly created maps of State Street. Each group had the opportunity to attach additional information such as photos they took of State Street to their presentation if they desired.

Data Collection

Data were collected for the Madison 2200 project using: a) clinical interviews conducted with each participant before and after the workshop: b) videotapes of the workshops; and c) field notes taken by project researchers. Students' land use plans were also preserved for review and analysis. Interviews included: a) open-ended questions about ecology and urban planning; b) novel urban planning scenarios;[2] and c) a concept map in response to the question, "How are

[2] Students were randomly assigned an A and B form of matched urban planning problems in pre- and post-interviews.

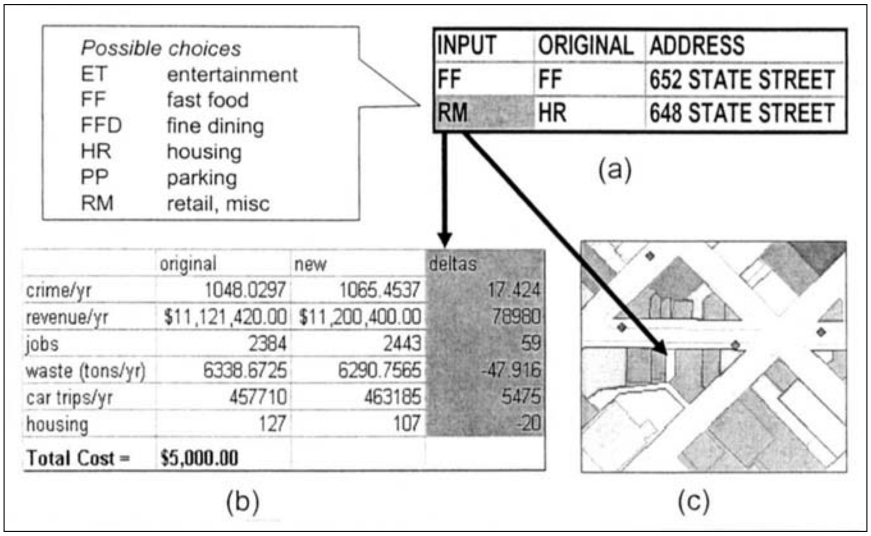

Figure 2. The workshop tools used in the design process: (a) a student makes a land use change in the shaded cell in the *decision space* on MadMod, (b) the change is numerically reflected on the workshop in the *deltas* column, and (c) the change is reflected spatially in ArcMap.

people connected to their cities?" Post-interviews also included questions about the workshop and students' experiences during workshop activities.

Data Analysis

Data were analyzed using a grounded theory framework (Glaser, 1978; Lincoln & Guba, 1985; Strauss & Corbin, 1998). Pre- and post-interviews from the workshop were transcribed and broken into excerpts. Each excerpt represented one complete answer to a question, and included any follow-up questions or clarifications between the student and the interviewer. Using a constant comparative method (Lincoln & Guba, 1985), emergent trends were identified and categories for coding were developed. Five analytic categories emerged from the data: Interconnectedness, Understands complexity, Planning practices, Use of model, and Open-endedness. (See Table 1 for definitions of codes and sample excerpts.) When qualitative analysis was completed, frequencies from each code were further analyzed using intra-sample statistical analysis (ISSA) to determine if statistically significant correlations existed between categories (Shaffer & Serlin, 2004). Significant correlations were then used as supplementary support for previously established qualitative findings.

RESULTS

Data in this section support three claims about the experience of students in the Madison 2200 project. First, students developed a deeper understanding of the domain of ecology and of their city as an ecological system. Second, this developing understanding was linked to the practices of urban planning and the interactive GIS model used to enact those practices in the workshop. And third, students were able to apply this framework of tool and practice to novel problem contexts.

The Development of Ecological Understanding

Definitions of Ecology

As compared to their pre-interview responses, in post-interviews, students were able to provide more extensive and explicit definitions of the term "ecology." For example, in the pre-interview, one student said:

> Ecology is . . . I'm not sure what that means; I guess I don't really know.

In the post-interview, the same student said:

> [Ecology is] the study of the ecosystem. Basically how one thing will affect the other thing. If something is removed or placed here, or something like that. Like increasing population might lead to a lack of jobs for people, and then it leads to more waste and traffic or something like that, that's like ecology in the city.

Only 9% of students (1/11) were able to offer a definition of ecology in the pre-interview, compared with 82% of students (9/11) in the post-interview ($p < 0.01$).

Ecological Interconnectedness

In their explanations of ecological issues in the post-interview, students gave more specific examples of how ecological issues are interdependent or interconnected than in the pre-interview. For example, when asked in the pre-interview whether there are connections between what happens in a city and what happens in the environment, one student said:

> [L]et's say we just had this new drink around and we just litter in the streets—it just depends, I don't know.

In the post-interview, the same student answered:

> [T]hey depend on each other; they affect each other, like they're interrelated. Like trees for example. Trees help reduce pollution while the city could be producing pollution, so they help create a balance.

Table 1. The Five Emergent Codes from Analysis of Interview Data

Code	Definition	Example
Interconnectedness	Explanation of how issues in a city are interdependent or interconnected.	Ecology is the relationship between people, places, and things. Everything is connected. I mean, people are connected, like people build the things and if people don't want the things in the city, then they're not going to stay long.
Understands complexity	Reference to more than one appropriately relevant issue and/or perspective in considering possible solutions to an urban planning or ecological problem.	I'm trying to please everybody. Like I'm trying to satisfy people and they also want their recycling plant, and all the waste, I don't know, if I was in this position, I'm trying to figure out what else they could take from, what's least important, but everything is important, if it goes into the whole system.
Planning practices	Explicit description of urban planning practices in solutions planning problems.	Yeah, like a planner you know, basically what we were doing like designing zoning areas, deciding how much space to distribute, how many people would be affected by that.
Use of model	Explicit use of elements of the city planning model to explain solutions to urban planning problems.	They could take more areas and sell more commercial spaces so that more people could open stores and they could generate more money for the city and they could regain money to rebuild the recycling plant. Of course it might have repercussions cuz you could like open up stores, then the crime would raise up . . . then we'd have a whole nother problem.
Open-endedness	Reference to multiple possible outcomes of the task, typically indicating how land use plans vary depending on how one approaches the problem and how one decides which constraints are most important to satisfy.	Well, there was no right or wrong way to design it, we got to do what we thought was best. Cuz you couldn't get it wrong. You just got to do what you wanted and what made sense.

Overall, there was a statistically significant difference in the number of references students made to interconnectedness between pre- and post-interview (see Figure 3; pre-interview mean = 3, post-interview mean = 13.09, $p < 0.01$).

Complexity of Urban Ecosystems

Concept maps showed an increased awareness of the complexities present in an urban ecosystem in the post-interview compared to the pre-interview. Figure 4 shows one student's concept maps made in response to the question, "How are people connected to their cities?" The post-interview map has both more nodes and more links than were present in the pre-interview. Overall, there was a statistically significant difference in the links and nodes they added to their concept maps from pre- to post-interview (see Table 2).

These more complex concept maps reflect a more sophisticated understanding of the conceptual space. As students completed the concept maps, they explained why they made the connections they chose. For example, during the pre-interview, one student said this about his concept map:

> Jobs are connected to the greenspace, if you're a gardener or someone who takes care of the parks or that. And traffic, it affects car pollution and then you also plan where streets have reduced pollution too, so that kind of affects each other, and crime is left over there. Jobs do create crime there because there are people who have jobs and people who don't have jobs, so they

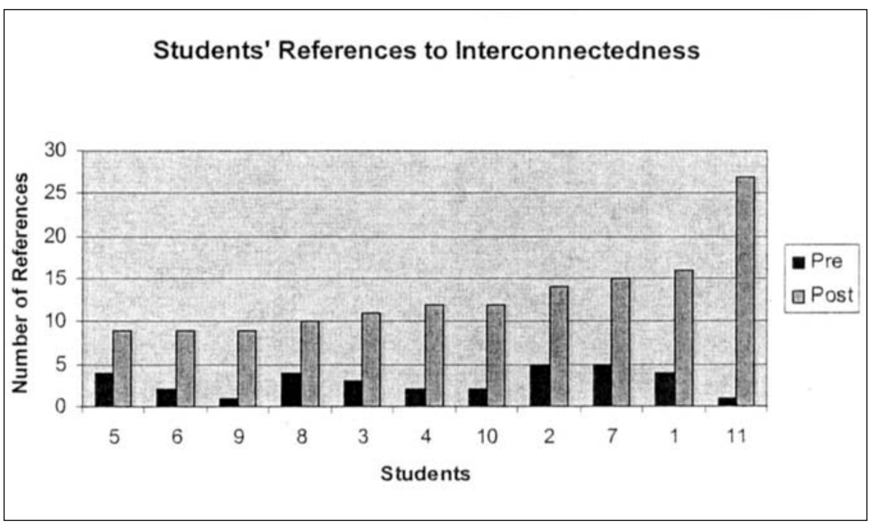

Figure 3. Students increased their understanding of interconnectedness. (Students have been ordered for clarity of presentation.)

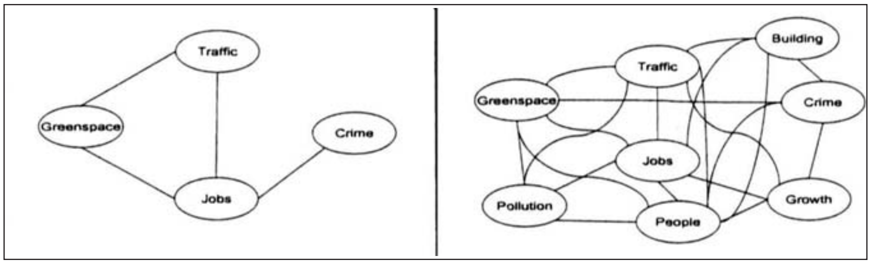

Figure 4. One student's pre (left) and post (right) interview concept map response to the question "How are people connected to their cities?"

Table 2. One-Tailed *T* Tests Detailing a Significant Increase in the Links and Nodes Students Placed on Their Concepts Maps from Pre- to Post-Interview ($p < 0.01$)

	Pre-interview mean	Post-interview mean	Pre-interview standard deviation	Post-interview standard deviation	*p*-Value
Links	6.55	11.27	2.34	4.52	$p < 0.01$
Nodes	6.90	8.27	2.63	2.88	$p < 0.01$

> don't have a source to get money from so they'll probably steal that or steal cars. I'm not sure I can't see too many other connections.

In the post-interview, the same student said:

> Well jobs can create crime because more jobs mean more money, and more money might mean more crime. And greenspace kind of attracts crime, because like if you had a really big park it would be easier for crooks and stuff to hang out. That's kind of an image that the parks give me, sort of. Then if you have traffic you're going to have pollution, so the best thing you can do is have greenspace to kind of fight that pollution. So, traffic produces pollution. Job produces pollution because of the trash that people accumulate like paperwork, and the pollution will affect the environment, either the air or the ground. Like and how about zoning? Well, people want greenspace, so it will create sort of a demand for it. Jobs would mean more people, more people would mean more pollution, which would mean more traffic, and more people would mean more crime. Like city-wise, like growth would mean more people, like it basically builds on each other, like one helps the other grow a bit. . . . When the city grows and the city has more people it's going to need like buildings to house them, or like jobs, like workplaces,

> you need buildings for that, and like if there are more buildings, there will be more traffic, more of everything, so everything is just connected to it. You can't really change one thing without changing another.

Role of Tool and Practice in the Development of Ecological Understanding

Students thus appear to have developed a richer understanding of urban ecology through their work in the project. In this section, we examine the role that features of the MadMod tool and elements of urban planning practice played in developing that understanding.

MadMod

When asked in the post-interview about elements of the workshop that helped them understand ecological issues, students referred to the interdependencies embedded in MadMod. For example, one student said:

> I learned a lot about ecology and city planning, and if you change one thing essentially everything else is going to be changing too. Chain effect and stuff like that. When we were changing stores with the model, we figured out that we'd have to not necessarily put in everything that we wanted because it cost money and we had to stay in a budget, but if we changed one thing then maybe the waste would go down but the jobs would go up maybe the housing would go down, so we had to look at all that.

Overall in the post-interviews, students consistently referred to the MadMod simulation model when explaining their understanding of the interconnectedness of urban ecological issues ($r = 0.628$, $p < 0.05$).

Urban Planning Practices

During post-interviews students also made frequent reference to urban planning practices when explaining their thinking about ecological interconnectedness. For example, when asked "Do you think it matters where physical structures (like buildings, houses, or parks) are placed in cities," one student replied:

> Yes, because, like, when it comes to parks, you wouldn't want to place a big old park where nobody goes and it's hard to reach, and when it comes to buildings, you wouldn't want to place a big building in the middle of a suburban area or in the middle of a busy street to cause clutter and confusion around the area. These are like, relationships you have to think about. You wouldn't put a big park with a lot of stuff made for people 45 minutes out of the way, and you wouldn't make it hard for people to reach. You have to have a good plan. Maybe make it in walking distance and maybe city busses can take the kids to it. So if the parents can't take them, they can give them money to go to the parks, but you wouldn't make it so hard to get to because then it wouldn't get its whole value . . . and, not necessarily a busy street, but

> you wouldn't take it and put it in a corner, like if this is a street and this is a dead-end (draws diagram with his hands), you wouldn't put a big old office building right there and then just come and disrupt the whole area and cause clutter in that area. I meant that you would rather have it in the industry or downtown where a big old building looks like it should go, where it can make money.

Overall there was a statistically significant correlation between students' references to urban planning and the interconnectedness of urban ecological issues ($r = 0.723$, $p < 0.05$).

The open-ended nature of urban planning problems and practices seemed to have been of particular importance to students in understanding ecological complexity. For example, when asked, "Did you learn anything from the workshop?" one student said:

> I learned a lot of stuff about thinking about what city planners do, getting a feel for what they do, that's kind of interesting. The scenario, like what we had to do, we had to redesign State Street, like zoning or destroying buildings or going to check out places to see what could be changed. There's a lot to it and there's like more than one way. Kind of like what city planners do, they go and like, they check out the area to see like what would be appropriate for like a park or a building and it's a hard decision.

Overall there was a statistically significant correlation between students' references to open-endedness and their understanding of the complexity of issues ($r = 0.708$, $p < 0.05$).

Students' Use of Their Ecological Understanding

Students developed a deeper understanding of urban ecology through the Madison 2200 workshop, and the tools and practices of urban planning appear to have played a significant role in shaping that change in students' thinking. In this section of the results, we examine the extent to which students were able to apply ecological understanding gained from the workshop to solve novel urban planning problems, and the role that tool and practice played in this process. In particular, we look at: a) how the workshop changed the way students viewed events in their real, everyday encounters with cities; and b) how students addressed hypothetical urban planning problems.

Real-World Experiences

During post-interviews, 100% of the students (11/11) said the workshop changed the way they think about cities. For example, one student said:

> I'm looking at connections a lot closer now, usually you'll see connections but you don't think about them as much as you do now, like you know that cars pollute the air and trees help create oxygen, but then after this you see

> a lot more different connections like between trees and buildings or why certain things are. Commercial areas are one way and why residential areas are another. I really noticed how they have to, when they think about building things they, like urban planners also have to think about how the crime rate might go up, or the pollution or waste depending on choices.

Most of the students (82% or 9/11) similarly said the experience changed the things they pay attention to when walking down a city street in their neighborhood. “You notice things,” said one student, “like, that’s why they build a house there, or that’s why they build a park there.”

Hypothetical Planning Problems

In the post-interview, students responded to novel, hypothetical urban planning problems, and their answers show increased awareness of the interconnection of urban ecological issues. For example, in pre- and post-interviews, students were asked to address the following urban planning problem:

> The Graham County Waste Management Committee is concerned about the growing amount of waste in the county. The waste levels are continually rising and landfill space is becoming a concern. The committee is currently trying to figure out how the amount of waste in the county can be reduced to a level that can be managed. What suggestions could you make to the Waste Management Committee that would help them develop and justify their plan.

Before the workshop one student responded:

> Uh, I mean, they could look for a new landfill, like a new place to build a landfill.

After the workshop, the same student responded to a similar problem dealing with the closing of the town recycling station:

> Okay, well, first of all, they should have not closed down the recycling plant. They could have cut other stuff, or they could’ve raised taxes to increase revenue, done surveys, or they could have made the zone larger with businesses so they could support the place if they were going to close it down I think they should keep a recycling plant because they should be helping to reduce the amount of waste which is what they’re trying to go for which is like their goal. But like closing down a recycling plant is going against the goal. They could export the trash I guess, but then that would cost a lot more money too. And they’re like making budget cuts, so they probably wouldn’t be able to afford that. Hmm, okay. I’d say fundraising . . . like, they could have a festival, like a big festival where it’s a kind of fair that attracts tourism and stuff. That would bring in money. You could rent the fairgrounds, charge for parking, and they can get a certain percentage from the fair people, like in a tax or something. Like a revenue tax.

Changes such as these suggest that students were able to mobilize understanding developed in the context of the redesign of one local street to think more deeply about novel urban ecological issues. Moreover, the data suggest that students used particular features of the interactive GIS model to think in an ecologically complex way about these urban planning problems. For example, in another problem that asked students to generate ways to fund construction of a new elementary school, one student explicitly referred to his experience with the MadMod model:

> He can probably just, isn't this kind of like what we did, how we had to raise the revenue, like he needs to raise the revenue by adding more things to the city that might help raise the revenue? Just like more stores that people could shop at, or more restaurants, more theaters, stuff that they do that people pay money for.

These post-interview urban planning problems show a statistically significant correlation between student references to the workshop model and the interconnectedness of urban ecological issues ($r = 0.615$, $p < 0.05$).

In summary, these results suggest that through participation in the Madison 2200 workshops students: a) developed an understanding of ecology and applied this new understanding to urban planning problems during the post-interview; and b) that urban planning practices and the features of the interactive GIS model used in the workshop played an important role in shaping the development of that understanding, and in its mobilization in novel contexts.

DISCUSSION

Ecology is the study of the interdependence between organisms and their environment. In order to understand ecology, students need to be exposed in some way to experiences that make visible that interdependence and appropriate complexity. Klopfer and Squires (in press) have shown that augmented reality learning environments can help to resolve the existing dichotomy between indoor technology environments and outdoor experiences by using mobile technologies in the context of nature exploration. In this way, it is possible to adapt technological tools once tied to an indoor classroom for use in authentic ecological settings. Augmented reality bridges reality and virtual reality using technology to supplement, rather than replace reality, and thus enables students to experience both simultaneously (Feiner, 2002).

Addressing the same issues from a different, yet potentially powerful perspective, the Madison 2200 project used an augmented *by* reality learning environment, which offers another method to bridge the qualities of outdoor education and technology-based learning. As in augmented reality learning environments, participating youth experienced both an outdoor environment *and* a simulated one. Rather than using technology to enhance their outdoor experience, however, here students took realistic action to determine a solution to a complex problem within their simulated, virtual environment by using real world tools and practices.

Following the theory of pedagogical praxis (Shaffer, 2004), the tools and practices students used to construct ecological understanding in the Madison 2200 project were mapped from the professional practices of urban planners, which have ecological principles embedded within them. Urban planners employ a particular way of thinking about and finding solutions to complex urban ecological problems. By using these practices, the Madison 2200 project provided students with an urban planning framework for thinking about urban ecology. In this augmented *by* reality learning environment, students engaged in a course of action that paralleled the decision-making processes and technological tools of practicing urban planners. As a result of using these tools and practice through their actions within the virtual simulation environment, students gained a functional understanding of ecology and they were able to apply that ecological understanding to situations in both real-world and hypothetical contexts in their post-interviews.

In *Democracy and Education*, John Dewey claimed that education is valuable:

> when the young begin with active occupation having a social origin and use, and proceed to a scientific insight in the materials and laws involved, through assimilating into their more direct experience the ideas and facts communicated by others who have had a larger experience (1916, p. 227).

In this study, students acted to solve a realistic urban problem. Working to solve that problem using authentic urban planning practices provided them with an opportunity to develop ecological understanding. The Madison 2200 project thus offers one potential method for instilling understanding of ecology in youth through participation in a simulation that incorporated the professional practices of urban planning. The results presented here suggest that these students did learn concepts in ecology by engaging in authentic urban planning practices using urban planning tools—and this conceptual development was linked to the technologies and practices of the profession. The qualitative nature of our data means that we can only explain the experience of a particular set of students in this particular learning environment modeled on the tools and practices of urban planning. However, these results do suggest that: a) simulations modeled on authentic professional practices offer a new method for developing ecological understanding; and b) the theory of pedagogical praxis may be an appropriate framework for furthering the development of such simulations.

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