Factors Affecting Technology Uses in Schools: An Ecological Perspective

Yong Zhao and Kenneth A. Frank

Am Educ Res J 2003; 40; 807
DOI: 10.3102/00028312040004807

American Educational Research Journal
Winter 2003, Vol. 40, No. 4, pp. 807–840

Factors Affecting Technology Uses in Schools: An Ecological Perspective

Yong Zhao
Kenneth A. Frank
Michigan State University

Why is technology not used more in schools? Many researchers have tried to solve this persistent puzzle. The authors of this article report on their study of technology uses in 19 schools. They suggest an ecological metaphor, using the example of the introduction of the zebra mussel into the Great Lakes, to integrate and organize sets of factors that affect implementation of computer uses. Their findings suggest that an ecological perspective can provide a powerful analytical framework for understanding technology uses in schools. That perspective points out new directions for research and has significant policy and practical implications for implementing innovations in schools.

Keywords: computers in schools, diffusion of innovation, educational technology, school ecology, teacher development.

> Zebra mussels were first sighted in the Canadian waters of Lake St. Clair in June 1988. By September 1990 they were found in all of the Great Lakes. After 1992, populations of zebra mussels spread rapidly throughout the eastern United States and Canada. The Zebra mussel has caused and continues to cause tremendous ecological changes in the Great Lakes (Vanderploeg et al., 2002). It has not only threatened native species but also led to the spread of other alien species over a wide area. In the last 15 years, the zebra mussel has greatly disrupted the fish communities in the Great Lakes. (Shuter & Mason, 2001)

Many scientists, policymakers, environmentalists, and concerned citizens are worried about the ecological and economic consequences of the rapid dispersal of the zebra mussel in the Great Lakes; at the same time, many educational researchers and practitioners, policymakers, and concerned citizens worry about the frustratingly slow adoption of computers and other modern technologies in schools. Although computer technology is quickly spreading to almost every part of our lives (much like the zebra mussel in the Great Lakes), the introduction of technology in schools has been less than successful. In the 20th century there were several waves of massive investment in technology to improve education, but none had a significant, lasting impact on education. Despite the generous investment in, and increased presence of, computers in schools (Anderson & Ronnkvist, 1999; Becker, 2000a; Cattagni & Farris, 2001), computers have been found to be unused or underused in most schools (Becker, 2001; Cuban, 1999, 2001; Loveless, 1996; Zhao, Pugh, Sheldon, & Byers, 2002).

Zebra mussels in the Great Lakes and computer uses in schools are of course quite different, but both are phenomena introduced into an environment where they are foreign. The introduction, survival, and dispersal of an alien species in a new environment are complex processes. To understand them requires a comprehensive and systemic approach that takes into consideration the nature of the species, the environment, other facilitative forces, and the interactions among these components. Because the ecological approach to understanding the successful invasion of the zebra mussels in the Great Lakes has been fruitful, we draw on this example to develop a framework for understanding computer uses in schools. In this article, we first discuss the need for a unifying theoretical framework in the context of existing research about computer uses in schools. We then propose a theoretical framework based on the ecosystem metaphor and present an empirical study that applies the metaphor. Finally, we discuss the implications of the framework for future research, policy, and practice.

The Need for a Unifying Framework

Concerns about the slow adoption of technology by teachers are not new. Many researchers have, from various angles, studied the phenomenon through different approaches, from case studies (Cuban, 2001; Schofield, 1995; Zhao et al., 2002), to historical analysis (Cuban, 1986), to large surveys (Becker, 2000a, 2001). They offer various accounts of why teachers do not frequently use technology to its full potential or in revolutionary ways that could truly lead to qualitatively different teaching and learning experiences.

Some researchers believe that schools, being the social organizations they are, are directly at odds with new technologies. The goal of schools as

YONG ZHAO is an Associate Professor of Learning, Technology, and Culture at the College of Education, Michigan State University, 115D Erickson Hall, East Lansing, MI 48824; e-mail *zhaoyo@msu.edu*. He also directs the Center for Teaching and Technology there. His research interests include technology adoption in schools, on-line education, and the social-cultural dimensions of technology.

KENNETH A. FRANK is an Associate Professor at the College of Education, Michigan State University, 460 Erickson Hall, East Lansing, MI 48824; e-mail *kenfrank@msu.edu*. He teaches counseling, educational psychology, and special education, as well as fisheries and wildlife, at the university. His substantive interests include the study of schools as organizations, social structures of students and teachers, school decision making, and social capital; his methodological interests include social network analysis, causal inference, and multilevel models.

organizations, according to Hodas (1993), is "not to solve a defined problem but to relieve stress on the organization caused by pressure operating outside of or overwhelming the capacity of normal channels" (p. 2). In other words, schools naturally and necessarily resist changes that will put pressure on existing practices (Cohen, 1987; Cuban, 1986). In addition to this inherent resistance to change, schools are also said to have a structure that prevents widespread uses of computers. Collins (1996), in a reflective essay on his experience with the Apple Classroom of Tomorrow project, cites limited classroom space and the bulky size of computers, teachers' unwillingness to take the students to the lab, and lack of access to computers at home as factors that limit the use of technology in schools. More serious problems, however, lie beyond technological or physical structures in the conceptual structure of schools.

> [T]he structure and conception of school that evolved in the last century is quite incompatible with effective use of new technologies. The view of teaching as transmission of information from teachers to their students has little place for students using new technologies to accomplish meaningful tasks. The forty-five-minute period makes it difficult to accomplish anything substantial using technology. (Collins, 1996, p. 61)

A more frequently cited set of factors affecting technology uses in schools is associated with the teacher (Becker, 2000a, 2000b; Hadley & Sheingold, 1993; Sandholtz, Ringstaff, & Dwyer, 1997; Zhao & Cziko, 2001). For example, the diffusion literature (e.g., Rogers, 1995) suggests that teachers' attitudes toward, and expertise with, technology often are key factors associated with their uses of technology (Becker, 2000a; Bromley, 1998; Hadley & Sheingold; Sandholtz et al., 1997; Smerdon, Cronen, Lanahan, Anderson, Iannotti, & Angeles, 2000; Zhao & Conway, 1999). Unless a teacher holds a positive attitude toward technology, it is not likely that he or she will use it in teaching.

Computer technology itself has also been named as the source of a set of factors that affect its uses. First, there are conflicting ideas about the value of technology and hence conflicting advice to teachers about how technology should be used in schools (Cuban, 1999). This leads teachers to a state of confusion about the educational value of technology. Second, the constantly changing nature of technology makes it difficult for teachers to stay current with new developments. Third, the inherent unreliability of technology makes it less appealing for most teachers (Cuban; Zhao et al., 2002). Because technology is inherently unreliable and can break down at any time, teachers may choose not to use it in their teaching unless there is a strong need for it and reliable support.

In summary, previous research has resulted in a long, almost exhaustive, list of factors that may affect the uses of technology in schools. However, these factors are often examined in isolation from each other or from the system in which they interact. Rarely are they studied together under a framework to sort out their relative importance and to identify the relationships among them. Moreover, there seems to be no framework in the existing literature that captures the dynamic nature of the technology adoption process. We have come up with a list of *what,* but we are short on *how.* Research in this area is in desperate need of a framework that can help to move the discussion beyond simple verification of the correlation between teachers' technology competency and use or simple addition of new factors to the "laundry list" of factors associated with technology uses. Also needed is a unifying framework for the current research, which approaches the issue from many perspectives: cognitive, social, organizational, technological, and psychological. To understand the process of technology adoption we need one framework that allows us to talk about these factors in similar terms.

The Ecological Metaphor: Learning from Zebra Mussels

To understand why the zebra mussel so rapidly invaded the Great Lakes ecosystem, ecologists must understand the interaction of ecological conditions, including characteristics of the invading species, characteristics of the existing species, temperatures, and other geographical characteristics. Similarly, to understand computer uses in schools, we can no longer continue the tradition of studying discrete factors in isolation. Instead we need to become "ecologists" and provide an organic, dynamic, and complex response to this organic, dynamic, and complex phenomenon.

The successful invasion of the zebra mussels in the Great Lakes has attracted much attention among ecologists and biologists, who have been eager to understand why this alien species from the Caspian Sea spread so rapidly in the Great Lakes and what changes it may bring about. After analyzing the successful invasion process and patterns of the zebra mussels and several Ponton-Caspian endemics that have recently entered the Great Lakes, Vanderploeg et al. (2002) found that the zebra mussel is an *r* strategist (*r* is a reproductive strategy in which energy is invested in a multitude of offspring that receive little or no parental care), has a high reproduction rate, and reaches sexual maturity within a year. It also has other characteristics of invasive aquatic species, such as wide environmental tolerance, mechanisms of rapid dispersal, genetic variability, and phenotypic plasticity. Coincidentally, all of the Great Lakes (except open Lake Superior), with the right amount of calcium concentration and comfortable temperature, offer a suitable environment for the growth and reproduction of the zebra mussel. The Great Lakes also provide rich food sources. The activity cycle of native unionid shells makes it possible for zebra mussels to wipe them out. Moreover, the zebra mussels do not have any natural enemies. Finally, they benefit a great deal from human activities: ballast water transportation facilitates the dispersal of the zebra mussels.

The successful invasion of the zebra mussel is a result of many factors working together. To accurately explain and predict its impact, we need to take into consideration the compatibility between its characteristics and the environment, and also its frequency of arrival in sufficient quantity. The emerging science of ecology, in particular the concept of ecosystem, can help us to examine this dynamic process by viewing the interactions of the parts with each other as well as their interactions with the whole. The ecological approach provides a powerful framework for understanding complex human social issues (see, for example, Bronfenbrenner, 1979, 1995; Bronfenbrenner & Ceci, 1994; Bruce & Hogan, 1998; Lemke, 1994; Nardi & O'Day, 1999). In the next three paragraphs, we identify the components and characteristics of ecosystems that will help us to lay a foundation for a unifying framework, which can then be used to understand the introduction and implementation of technology in schools.

The word "ecology" comes from the Greek *oikos,* meaning "household," combined with the suffix *logy,* meaning "the study of." Thus the discipline of *ecology* is literally the study of households, including the plants, animals, microbes, and people that live together as interdependent beings. It is a discipline that has increasingly emphasized holistic studies of both parts and wholes (Odum, 1997).

A fundamental concept in ecology that enables the holistic study of both parts and wholes is *hierarchy,* a way of arranging things in graded compartments. An *ecosystem* is the lowest level in the ecological hierarchy; it is complete with all the necessary components for function and survival over the long term. An ecosystem is an open and dynamic system, with things constantly entering and leaving. But ecosystems have the tendency or ability to achieve *homeostasis* or internal equilibrium, a key ecological phenomenon. That tendency or ability is found at all levels of the ecological hierarchy.

Ecosystems contain both *abiotic* and *biotic* communities. The abiotic part of an ecosystem consists of its inorganic components; the biotic part consists of populations of organisms or species. A species must have a *habitat*—the place where the species lives—and a *niche*—the role that the species plays in the system. The biotic component of a functional ecosystem has many species, each playing a unique role and occupying a unique habitat. In most natural communities, there are a few species that are common, called *dominants,* while a comparatively large number of species are rare. The rare species can be as important as the dominant ones. The most important species in an ecosystem are called *keystone species,* which exert some kind of controlling influence over the system although they may not be dominants (Odum, 1997).

To construct a unifying ecological framework that is useful in an analysis of technology uses, we need first to establish four metaphorical equivalents: (a) Schools are ecosystems; (b) computer uses are living species; (c) teachers are members of a keystone species; and (d) external educational innovations are invasions of exotic species. These metaphorical bridges are intended to help us apply what we learn from ecological examples to our current task of understanding technology uses in schools.

Schools as Ecosystems

Viewing human institutions as ecosystems is not new. Bronfenbrenner (1979, 1995) has long been a champion in developing theories and conducting research about human development from an ecological perspective (also see Bronfenbrenner & Ceci, 1994; Brofenbrenner & Morris, 1998). In addition, Lemke (1994) uses the term "ecosocial system" in his application of the ecological approach to the study of cultural change.[1] We contend that a school and its classrooms can be viewed as an ecosystem because they make up a complex system containing many parts and relationships, with both biotic components (e.g., teachers, students, parents, and administrators) and abiotic components (e.g., physical setting, location of the computers, grades, and subjects taught). Within the school, teachers, librarians, students, books, dictionaries, projection devices, workbooks, desks, and other "species" interact with each other in certain ways to form a system that enables learning to take place. A school exists as a complete unit necessary for functioning over a long period of time in a hierarchical structure. It is nested in a school district, which in turn is part of a state educational system that is part of a national education system. Just as in a biological ecosystem, the teaching ecosystem exhibits *diversity* in that it contains many types of species, each having a different set of characteristics and playing a different role (occupying a unique niche) in ecological terms. The species' characteristics and roles constantly affect one another, thereby constantly modifying their interrelationships.

Computer Uses as Living Species

Studying the environment is not sufficient, as we have learned from the case of the zebra mussel. We need also to study the invading species, in this case, computer uses. Some readers may think it is a stretch for us to treat computer uses as biological organisms. However, we believe that this is a reasonable interpretation of the metaphor. Although technologies are not exactly the same as living creatures, they seem to follow a similar process of evolution. That is, diverse human needs, experiences, and talents lead to the development of diverse technologies. Some of the technologies are judged to be more useful, or fit for the task, than others, and they survive while others perish that are judged to be less fit. Therefore, new needs bring about "fittest of the moment" technologies, which are based on existing technologies. Again, some of the new technologies will be judged more fit than others and will survive and generate new variations, while others, less fit, will disappear (see also Basalla, 1988; Cziko, 1995; Levinson, 1997).

Teachers as Members of a Keystone Species

In an ecosystem we observe constant species-to-species interactions like the ones between the zebra mussel and native mussels. As we consider these interactions, we should not ignore the fact that individual members of a species also interact with each other. The patterns of interaction within species can resemble those between species. Members of the same species can compete as well as cooperate with each other. In effect, although genes are fundamentally "selfish," they can establish cooperative relationships or exhibit cooperative, even selfless, behaviors. The fact that so many animals live in groups is a telling example (Dawkins, 1989). Some species even show behaviors that appear to contradict the idea of "being selfish." Bees, for example, die for their fellow bees, and some ants detonate themselves to protect the colony (Wright, 1994).[2] Various theories have been forwarded to explain the rampant altruism observed among ostensibly selfish animals and human beings. One of the explanations is called *reciprocal altruism* (Dawkins; Wright), which can be simply summarized as, "If you scratch my back, I'll scratch yours."

Teachers as human beings are also fundamentally selfish in that they are concerned primarily with the well-being of their own classrooms (Lortie, 1975). But they also live and work in social groups and know that at times they may need help from others in the organization. Following the principle of reciprocal altruism, teachers may help and respond to members of their common organization, the school, to promote the well-being of the school. This reciprocal altruism enables selfish beings to work together, give and find help, and build their social capital.[3]

External Educational Innovations as Invasions of Exotic Species

Our last metaphorical bridge likens innovation to an invasion of an ecosystem by a foreign species. As mentioned before, an ecosystem has the tendency or ability to maintain internal equilibrium. The introduction of new species, whether intentional or unintentional, affects the equilibrium to varying degrees. When a new species, such as the zebra mussel, enters an existing ecosystem, it essentially is an invader from outside. The invading species may interact with one or more existing species. Depending on the properties of the invader and of the existing species, as well as on the types of interactions, several consequences may result: (a) The invader wins and wipes out the existing species; (b) both win and survive, in which case some other species may perish or the ecosystem may eventually become dysfunctional because of its limited capacity; (c) the invader loses and perishes; and (d) both the invader and the existing species go through a process of variation and selection and acquire new properties.

We have chosen to view computer uses introduced into schools by techno-enthusiasts as invading species. Whether they are successfully adopted and become permanently established depends on their compatibility with the teaching environment.

A Unifying Framework: Understanding Technology Uses in Schools

We now turn to the development of a framework for understanding technology uses in schools from an ecological perspective. We treat the frequency and types of computer use by teachers as indicators of the well-being of the computer-species in the school ecosystem.

Computer uses in schools can be divided into two major categories based on their purposes: (a) uses for students, and (b) uses for teachers. Teachers may apply technology for their own professional use (e.g., to develop materials) but not for their students (e.g., for student presentations), or the reverse. This distinction aligns with our application of the ecological metaphor at multiple levels. When a teacher uses computers for her own purposes it benefits her directly at the micro level as an organism, perhaps making her more efficient or engaging her interest. On the other hand, students are the common resource of the system. Thus, when a teacher facilitates student uses of computers, she contributes more directly to systemic value, which may have less direct and immediate personal benefits. Of course, the distinction between teacher and student uses and benefits is not pure. For example, if teachers gain efficiency through their own use, their efficiency may improve learning and have immediate systemic benefits; or, when teachers facilitate student use, the students' involvement may benefit classroom management. We treat each type of computer use as an individual species; student uses benefit everyone in the school, whereas teacher uses benefit the individual teacher. We treat the frequency of computer use for each purpose as representing the size of the population of each species.

Qualities of the Invading Species and Characteristics of Computer Uses

Two sets of factors affect the population or well-being of the invading species: (a) qualities of the species, and (b) interactions with existing species and the ecosystem environment. Dawkins (1989) suggests that, like successful genes, successful ideas (or *memes*—a term he coined to refer to ideas considered in a biological sense) have three qualities: longevity, fecundity, and copy fidelity.[4] In the case of computer uses in schools, the longevity of a particular practice with the computer means how long the practice is sustained. Uses that last longer have a better chance of being imitated by others. In more practical terms, when a certain use is championed by one teacher over a long period of time or promoted through sustained professional development efforts, it is more likely to survive.

The term *fecundity* refers to the ability of some *memes* to replicate themselves, or propagate, faster than others. Thus, when we refer to fecundity of computer technology uses, we mean the capacity of some uses to spread more quickly than others. In the case of schools, the concept of fecundity can help us to understand which types of uses are introduced to more teachers and are more likely to endure. Furthermore, an ecosystem that enhances the fecundity of a particular gene provides that gene with more opportunity to be successful. Thus in schools where teachers have more opportunity to work together with computers, we may see computers used more often.

Dawkins argues that *memes* blend into larger complexes and that although they can be large or small, they will maintain uniqueness within the larger unit even when they seem to mutate or blend with other *memes*. Furthermore, he contends that even though evolution seems to be a good thing, "nothing actually 'wants' to evolve" (p. 18). The need for copy fidelity, or accuracy of copies, would work against the evolutionary process, which looks for variation—errant copies of the original. In the end, although *memes* work hard to make exact copies of themselves, evolution will occur. We see the same tension with computer uses: Innovators often want their idea to be implemented or replicated faithfully by others, but changes or variations on the idea are inevitable (see also Tornatzky & Fleischer, 1990).

Interacting with the Environment and the Role of the Teaching Ecosystem

The survival of an invading species is determined not only by its own life-history characteristics but also by the compatibility of those characteristics with the new environment. In the case of computers in schools, the characteristics of the new environment are determined by the teaching context (see Figure 1). A given teaching context is nested within a multilevel ecological hierarchy, including government agencies, societal institutions, local community organizations, and the school bureaucracy. There is strong institutional demand at both the governmental and the societal levels to place computers in

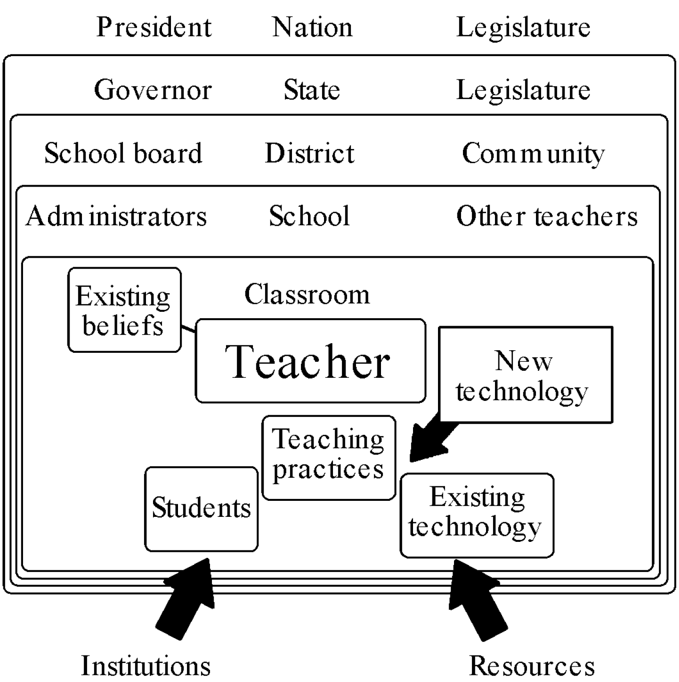

Figure 1. **The school ecosystem.**

classrooms, even if there is debate about the educational value of computers. Although societal institutions and federal and state policies are remote from individual classrooms, they undoubtedly penetrate teachers' immediate contexts to affect technology use. Thus both societal and governmental institutions can be thought of as geological forces that shape the general landscape of the school (or perhaps as suns that provide the energy) and thereby have some effect on how and to what degree teachers use technology. The school district is the more immediate system with which computer uses in the school need to be compatible. If the school district provides sufficient resources to support computer uses, those uses are likely to spread more quickly.

Schools and their social contexts shape the local and immediate ecosystem where computers are used. Schools can provide release time giving teachers opportunities to engage technology, and teachers can exert pressure on each other to use computers or can provide contextualized information about the their value and uses. The school is analogous to a specific area of the waters of the Great Lakes where the zebra mussel settles and interacts with local species and physical and physiological conditions. Technology infrastructure (network, location of computers, and availability of computer hardware and software), scheduling, the physical layout of the building, and the subjects and grades that teachers teach make up the abiotic component of the school ecosystem, which influences the types and frequencies of uses. For example, some subject matters and grade levels are more conducive to certain types of computer uses. Technology education, computer education, and business are subjects that have unfilled niches for one category of computer uses (teaching technology as the subject content), while special education courses provide the opportunity for the drill-and-practice category. The physical locations of the computers (e.g., distributed in classrooms or concentrated in the computer labs) also create different patterns of computer uses.

Teachers, administrators, librarians, media specialists, technology coordinators, students, and existing uses of other teaching and learning tools (e.g., books, copying machines, and telephones) make up the biotic component. Computer uses may compete for resources with any one of these species. For example, when students use the Internet as a source of information, they will rely less on the school library's print media; thus more funds may go to support Internet uses than to the traditional library. A more interesting and complex example is the use of computers to support student-centered project-based learning, as envisioned by many constructivist proponents of computers. This type of computer use competes with the teaching styles of some teachers, especially those who espouse a traditional teacher-centered approach. It may also be incompatible with the need to prepare students for standardized tests.

Interacting with Keystone Species and Teachers' Analysis of Use

In the final analysis, the survival of computer uses is determined largely by their compatibility with the aims of teachers, who are the keystone species in the ecosystem (again, refer to Figure 1). Previous research on successful adoption of educational change has focused on various groups (e.g., teachers) in schools and communities that are critical determinants (Louis, Toole, & Hargreaves, 1999). One way to look at the extent to which teachers adopt and use computers is through rational choice theory (Louis et al., 1999). Rational choice theory focuses on how changes in environmental conditions affect the action arenas where individuals such as teachers are making operational decisions. In these situations, individuals act in ways that have a positive effect on their perceived self-interest. We view teachers as purposeful and rational decision makers who, in the face of an innovation, behave like any species facing the introduction of a new species into its environment. This is not to suggest that teachers actually pull out a spreadsheet and compute the costs and benefits of computer uses. Nor is it to say that teachers' decisions are based on complete information and or are necessarily optimal in terms of educational value. In fact, we would argue that teachers very often make decisions based on limited information (Simon, 1957) and in response to pressure.

In the ecosystem metaphor, rational choice is manifest during the interaction between two species. This interaction is a dynamic process, wherein the species co-evolve and adapt to each other. For example, teachers can change their attitudes toward computers and reinterpret the functions of computers over time. Such reinterpretation leads to different realizations or uses (Bruce, 1993). Thus when teachers are given the opportunity and resources to experiment with computers, they may improve their technology proficiency and see how computers further their goals, that is, reduce perceived costs and increase perceived benefits. In addition, within-species interactions and reciprocal altruism are very important: Teachers may pressure each other or help each other, or both, depending on the norms of the social group. Pressure to use computers can turn into a perception of benefits because by using computers a teacher conforms to the pressure and retains her membership in the social system.

To summarize, although there are many possible influences at multiple levels of the educational hierarchy, two factors ultimately determine the degree and types of computer use by teachers: (a) the nature of the uses, and (b) the result of the teacher's analysis of the uses. All other factors contribute to these two. In other words, most factors do not directly influence technology uses in a linear fashion; rather, their influence is mediated or filtered by teachers' perceptions. Therefore, our framework places emphasis on the dynamic process between the teacher and the computer. We have chosen to highlight "opportunities" or "practices" that may affect teachers' perceptions rather than merely to seek static correlations between isolated factors and computer uses.

Testing the Framework

To test our framework, we conducted a study of technology uses in 19 schools. In this section, we describe the methodology of the study, including sample, data-collection, and data-analysis procedures.

Sample

Because of our interest in understanding how institutional factors may affect technology use, we chose whole school districts as our first level of analysis, a total of four districts from one Midwestern state. Because we also wanted to assess technology uses and understand what might affect the levels and types of technology use in schools, we needed to study schools that had technology available to teachers and students. Thus we selected schools that had made significant investments in technology between 1996 and 2001. Operationally, our criteria for selecting districts for participation in the study included (a) recent passage (between 1996 and 2001) of a bond referendum or receipt of a community foundation grant for implementation of technology; (b) willingness on the part of the superintendent of schools to participate in the study; and (c) a district size that would allow us to include all of the elementary schools in the district.

Because we wanted to study the social dynamics of technology implementation as a self-contained, well-bounded system comparable to an ecosystem, we focused on elementary schools that were relatively small and tightly defined as social systems. We were also interested in understanding possible building-level differences, so we included all elementary schools in the selected districts. To obtain a complete picture of technology uses, we administered the survey to all school staff. To come as close as possible to enumerating the entire faculty population, we offered incentives to individual teachers and to schools for high response rates. Ultimately, we achieved a response rate of 92% or greater in each of the 19 schools selected.

Table 1 presents background information on the sample school districts. These data suggest that our sample's access to technology was greater than the national average (Cattagni & Farris, 2001). We also compared our sample with other schools in the same state on other background variables. Not surprisingly, students who attended the sample schools came from families with slightly higher-than-average incomes, as indicated by the percentages of students who qualified for free or reduced-cost lunch. However, the sampled schools were not substantively different from other schools on other measures, such as per-pupil expenditures, student-teacher ratio, and school size.

Table 1
Background Information on Districts

District	Student population	District type	Student–computer ratio[a]
A	2,041	Rural/suburban	5.1
B	5,111	Suburban	4.9
C	1,638	Rural/suburban	2.9
D	7,158	Rural/suburban	4.4

[a]The student–computer ratio is the average for all district instructional computers as of March 2001.

Data Collection

We collected three types of data: (a) survey of all staff; (b) interviews with administrators and technology staff; and (c) interviews and observations in one focal school in each district. The survey included 33 format items (e.g., Likert-scale, multiple-choice, and fill-in-the-blanks items). The interviews were semistructured, loosely following a set of questions about technology infrastructure, policy, investment, and beliefs regarding technology. The interviews were conducted with the district superintendent, district technology director (or equivalent), principal of the focus school, and three to five teachers in each focus school. The observations focused mainly on the technology infrastructure of a building. The data collection was completed in spring 2001. A professional independent research firm was contracted to perform the data collection.

Data Analysis

The data analysis consisted of two stages. First, we gathered descriptive information regarding current technology uses in schools. Second, we identified influences that could affect technology uses, based on our review of the research on technology uses in schools and the research on the diffusion of innovations. In creating our ecosystemic model we organized those influences into six factors: (a) the ecosystem; (b) the teacher's niche in the ecosystem; (c) teacher–ecosystem interaction; (d) teacher–computer predisposition for compatibility; and (e) opportunities for mutual adaptation. A detailed description of the measures that we used to operationalize our constructs is provided in the Appendix. We then estimated relative effects of the factors by using multiple regression.[5]

Findings: Interpreting Technology Uses From an Ecological Perspective

In this section, we report our findings on current uses of technology in schools and describe measures of the possible influences on computer use in schools, accompanied by our statistical results.

Current Technology Uses in Schools

We set out with two major questions about technology use in schools: To what degree are technologies used in schools? And how are teachers engaged in technology use?

To What Degree Are Technologies Used in Schools?

Table 2 presents the percentages of teachers who reported various frequencies with which they used common school technologies for educational or professional purposes. The most frequently used technologies

Table 2
Frequency of Technology Uses by Teachers

Technology type	Never (%)	Yearly (%)	Monthly (%)	Weekly (%)	Daily (%)
Telephone system ($M = 4.76$)	0.50	0.20	2.10	16.90	80.30
Voice mail ($M = 3.72$)	12.60	6.80	13.30	30.60	36.70
Video/TV network ($M = 3.4$)	9.60	9.40	32.30	28.80	19.90
Internet ($M = 3.96$)	3.70	3.70	18.00	41.20	33.30
E-mail ($M = 4.62$)	3.30	2.30	4.20	9.80	80.40
Computers in school lab ($M = 3.45$)	10.50	10.10	11.00	60.70	7.70
Computers in classroom ($M = 4.57$)	5.10	0.70	4.10	11.70	78.30

Note. % = percentage of teachers reporting each frequency of use.

are e-mail, telephone systems, and computers in the classroom. This finding is consistent with an ecological metaphor in which simpler technologies requiring little adjustment to existing practices are more frequently used. We were interested to see that teachers use computers more in the classroom than in the computer lab, which is somewhat contrary to the observations of Loveless (1996). The difference may be due to recent investment in better and more numerous computers in the classroom. In addition, computers in the classroom are more convenient for teacher use, especially for simpler functions such as surfing the Internet and processing e-mail.

Note that although little previous research has addressed the use of telephones, they are used almost daily. Although a less complex technology than the computer, the telephone can be a powerful communication tool for teachers. Frequent use of the telephone could help a teacher who is isolated in the schoolhouse (Tyack & Cuban, 1995) or classroom (Lortie, 1975) to connect with parents, colleagues, other schools, and community members. The phone is critical in integrating the various layers of the ecosystem.

Drawing on the ecological metaphor, the various school technologies can be considered potentially complementary or competitive. Clearly, a telephone system and voice mail can be complementary, with teachers having the capacity to engage in conversation or take messages with the technology. There are also examples of video and TV networks that are integrated with computer technology. But perhaps less frequently considered is the potential for technologies to be competitive. If teachers rely increasingly on telephones for communication, they may have less need of e-mail. Similarly, if teachers rely on video and TV for electronic presentations, they may not need PowerPoint for such presentations. Clearly, from the anatomical standpoint these are different technologies. But when we consider them as part of an ecosystem, it is clear that they may compete for the same niche—that is, the same function in the teacher's professional life.

How Are Teachers Engaged in Technology Use?

In addition to frequencies of use of various technologies, we focused more narrowly on the various types of computer uses in schools. Here we go beyond asking about amounts of time spent by teachers or students using computers and ask *how* computers were used. Computers, unlike telephones, have qualitatively very different types of uses. The ecological metaphor applies here as well because the study of an ecosystem focuses on the ways that species interact rather than on simple frequency of interaction. As previously discussed, we differentiate between teacher computer uses and student computer uses; we consider the motivations of the teacher as selfish organism and as member of a system, as if we were studying species in an ecosystem.

Table 3 presents the percentages of teachers and students who used computers for various activities at various frequencies. The overall reliability of the measure of student uses is .75; the overall reliability of the measure of teacher uses is .66 (the latter is based on only three items, with correlations ranging from .36 to .42). The most frequent types of uses were by teachers, who used the computers for communication with parents and preparation for instruction; the least frequent were activities directly involving students in using the computers (e.g., student-to-student communication, remediation, and student inquiry). This finding again confirms the assumption that simpler technologies that require little change—and therefore cost less in terms of time and energy—are used more frequently. As we know, computers have a broad range of uses, some more complex than others. Teachers' communication with parents and preparation for instruction are much simpler to implement than are uses that involve students, because the latter require teachers to reconfigure their teaching practice.

The information presented in Table 3 also suggests that teachers use computers more for communication with parents than for communication with students. In light of teachers' frequent use of the telephone, we may hypothesize that teachers have a strong need to break down walls (Lortie, 1975)—that teachers need to communicate with parents and colleagues, although the current technology was absent at the time of Lortie's study. Speaking ecologically, teachers' need to communicate was an empty niche that this type of computer use eventually filled. Teachers' infrequent use of computers for communication with students may be explained by the fact that, at present, most communication with students occurs face-to-face in the classroom.

It seems evident that, like organisms in an ecosystem, teachers use computers in ways that address their most direct needs, bring them maximal benefits, do not demand excessive time to learn, and do not require them to reorganize their current teaching practices. Thus teachers' choices of computer activities minimize costs.

Influences on Computer Use in Schools: An Ecosystem Model

In this section, we describe our use of multiple regression to evaluate the relationships among the factors that may influence the degree and types of

Table 3
Frequencies of Computer-Using Activities

Activity	Never (%)	Yearly (%)	Monthly (%)	Weekly (%)	Daily (%)
Teacher use of computers					
Preparation for instruction (e.g., lesson and unit planning, downloading materials such as pictures) (*M* = 3.57)	8.60	6.90	26.70	34.30	23.60
Communication with parents (e.g., through newsletters, e-mail, class website) (*M* = 3.38)	11.20	5.60	29.50	41.00	12.60
Teacher-student communications (e.g., responses to written work, posting of schedules and activities) (*M* = 2.75)	34.00	7.90	21.40	21.90	14.80
Student use of computers					
Classroom management and/or incentives for students (e.g., rewards for completed work) (*M* = 2.68)	36.80	7.70	17.80	26.20	11.50
Record keeping (e.g., grades, attendance, IEP) (*M* = 2.39)	48.40	7.60	15.00	14.10	14.80
Student inquiry (e.g., student research using electronic databases, WebQuest) (*M* = 2.17)	42.10	13.10	31.20	12.60	1.00
Student-to-student communication (e.g., publishing of student work on a website, messages between keypals, e-group projects) (*M* = 1.54)	73.30	8.00	11.20	6.10	1.50
Core curriculum skills development (e.g., drill and practice on MathBlaster or Reader Rabbit) (*M* = 2.96)	26.20	3.60	29.60	29.10	11.50
Remediation (e.g., repeating a lesson, Accelerated Math, Jostens-type systems) (*M* = 2.42)	47.50	4.40	18.00	19.00	11.10
Development of basic computer skills (e.g., keyboarding, mouse skills, trouble-shooting) (*M* = 3.02)	27.40	4.10	15.30	45.10	8.00

Note. The IEP (Individualized Education Program) is a requirement of the Individuals with Disabilities Education Act Amendments of 1997; it is a written statement of specific services and strategies to meet the individual's educational needs. WebQuest is a popular teaching activity that engages students in using the Web to conduct research. MathBlaster, Accelerated Math, and Reader Rabbit are math and reading computer programs commonly used in schools. Jostens is a computer-based integrated learning system that is often used in schools; the term is also used for systems that resemble the one with the Jostens brand name.

computer use by students and teachers. We present findings from interviews and observations along with the survey results. We use the ecosystem metaphor to organize the presentation, reporting increases in R^2 as a result of adding the factors, or influences, on computer use (see Table 4). We restrict our discussion to factors with standardized coefficients of magnitudes greater than .1, with $p < .05$. However, we take relationships with standardized coefficients between .07 and .1 and statistically significant at $p < .10$ as suggestive.

The Ecosystem

Our findings support a richly contextualized set of influences that we interpret with respect to the ecosystem metaphor. To begin (see the bottom of Table 4), there were moderate differences among districts (districts accounted for about 11% of the total variation in student computer uses and 14% of the total variation in teacher computer uses).

Our observations and interviews suggest that the four districts, indeed, had different practices and policies for the purchasing and distribution of technology hardware and software, as well as for the focus and content of professional development. For example, one district took a more concerted approach to professional development approaches than did the others. In this district, professional development efforts were sequenced so that every teacher could start with basic skills and then move on to curriculum integration. This district also offered separate professional development programs for new teachers during the summer. The district technology director was adamant about having teachers within her district, rather than outsiders, lead professional development programs. District-level technology leaders were very responsive and continuously assessed teachers' needs in professional development, software, and hardware. Such practices were not observed in the other three districts, which appeared less responsive to the context of the teacher. Professional development in the other three districts was less systematic and less organized.

Regardless of whether the school or the district is considered to constitute an "ecosystem," most of the variation in computer use fell within ecosystems rather than between them.

The Teacher's Niche in the Ecosystem

The teacher's niche, defined by his or her structural location—part of the abiotic component—had large effects on use. Teachers of English were especially likely to use computers, and teachers in the upper grades were moderately more likely to use computers. Our observation and interview data suggest that English teachers found computers a natural tool for student writing activities. Just as the zebra mussels filled an unoccupied niche in the Great Lakes, computer use as a word processing tool found an empty niche in the English classroom.

Table 4
Factors Affecting Technology Uses in Schools

Factors	Student use of computers: Unstandardized coefficients (*SE*)	Student use of computers: Standardized coefficients	Teacher use of computers: Unstandardized coefficients (*SE*)	Teacher use of computers: Standardized coefficients
Intercept	.0369 (.280)		.4793 (.346)	
Opportunities for mutual adaptation		R^2 = .52		R^2 = .43
Exploring new technologies on own	.0524 (.043)	.057	.1852*** (.054)	.174
Seeking help from others, both in and outside school	.0800[a] (.048)	.073	.0436 (.060)	.034
Reading professional journals about new technologies	.0837[a] (.045)	.076	−.0036 (.055)	−.003
Teacher–computer predisposition for compatibility		R^2 = .51		R^2 = .40
Perceived compatibility	.1105* (.047)	.123	.1714** (.058)	.165
Perceived complexity	.0318 (.032)	.039	.0578 (.040)	.061
Perceived relative advantage: Belief that computers can help the teacher	.1065[a] (.054)	.113	.2007** (.067)	.185
Perceived relative advantage: Belief that computers can help the student	−.0426 (.059)	−.038	−.1154 (.073)	−.090
Teacher–ecosystem interaction		R^2 = .46		R^2 = .32
Help from close colleagues	.0082** (.003)	.103	.0007 (.004)	.007
Help from others who are not close colleagues	.0020 (.002)	.049	−.0008 (.002)	−.016
Pressure to use computers	.0284 (.027)	.044	.0779* (.033)	.104
Presence of competing innovations	−.0922** (.033)	−.114	−.0729[a] (.041)	−.078
Playfulness (experimenting with district-supported software)	.1693*** (.044)	.188	.0973[a] (.055)	.094
Location of exposure (attending district or school in-service programs)	.1185[a] (.068)	.072	.1229 (.084)	.065

(continued)

Niches accounted for increases in R^2 of 7% to 20%, thus supporting arguments that simple structural positions differentiate adoption rates. Combining the effects of district with teacher's niche, we can see that the "abiotic component" of teachers' instructional ecosystem accounts for a large portion of the variation. This finding is consistent with the ecological metaphor, which suggests that compatibility between the life-history characteristics of the invading species and the conditions of the new environment is critical to the success of the invader.

Table 4 (Continued)

Factors	Student use of computers: Unstandardized coefficients (*SE*)	Student use of computers: Standardized coefficients	Teacher use of computers: Unstandardized coefficients (*SE*)	Teacher use of computers: Standardized coefficients
Teacher's niche in the ecosystem		R^2 = .32		R^2 = .21
Teaching English	.4481***	.247	.2999**	.143
	(.090)		(.111)	
Grade level	.0727**	.189	.0395	.089
	(.023)		(.029)	
Teaching multiple grades	−.0695	−.036	−.0163	−.007
	(.116)		(.143)	
Missing grade information	.0620	.020	.3276[a]	.090
	(.160)		(.198)	
The ecosystem		R^2 = .11		R^2 = .14
District A	.3131	.185	.4399	.225
	(.112)		(.138)	
District B	.1735	.090	.2406	.108
	(.123)		(.152)	
District C	.4605	.190	.0048	.002
	(.126)		(.156)	
Sample size	383		386	

Note. Figures enclosed in parentheses represent *SE*.
[a].05 ≤ p ≤ .10.
* p ≤ .05. ** p ≤ .01. *** p ≤ .001.

Teacher–Ecosystem Interaction

Moving up in Table 4, teacher–ecosystem interaction accounted for an additional 11% to 14% of the variation explained. Teachers who perceived pressure from colleagues were more likely to use computers for their own purposes, and teachers who received help from colleagues were more likely to use computers with their students. The following accounts from two teachers confirm the importance of the social process:

Teacher 1: The process for the new Scholastic series was to preview it, to see what fits for a particular unit I'm teaching, and word of mouth. This process has worked pretty well. I can honestly say I probably wouldn't do certain things if someone hadn't told me about it or if we didn't have the series, because computers are very scary to me!

Teacher 2: Often, a lab technician learns the technology first or another teacher becomes familiar with it, paving the way for adoption in another classroom.

Here, the rationality of social capital is presented within the context of the ecological metaphor, suggesting that within-species interactions play a significant role as well in the fate of the invading species. Immediate and contextualized help from colleagues can address concerns about technical obstacles that can disrupt learning time in using computers with students. Furthermore, teachers' own actions may be more responsive to local social contexts, including social pressure from other teachers.

There is strong support for the ecological hypothesis that new species compete with each other. Teachers who perceived their school as implementing many new innovations were less likely to introduce new student uses for computers and moderately less likely to use computers for their own immediate goals. There was also strong evidence that teachers who had opportunities to experiment with district-supported software used computers more for student purposes than for their own purposes. It is noteworthy that, although based on self-report, the opportunity to experiment with technology is related to teachers' behaviors, suggesting that both perceptions of the ecosystem and interactions with it are important.

Teacher–Computer Predisposition for Compatibility

The teacher–computer predisposition for compatibility accounted for an additional 5% to 8% increase in R^2. Most important, the more strongly a teacher believed that computers were compatible with her teaching style, the more often the teacher reported using computers for herself and with her students. Like all professionals, teachers use their judgment and understanding of the local context to evaluate the value of innovation. This confirms the findings of Tornatzky and Klein (1982) but is also consistent with the ecological metaphor under the concept of mutualistic interactions with the invading species. Finally, teachers who perceived a relative advantage of computers for themselves reported more use for their own purposes and moderately more use for their students. Again, this result confirms Tornatzky and Klein, but casting it as relative advantage within the ecosystem metaphor helps us to understand why teachers' perception of an advantage to themselves (as opposed to teachers' perception of an advantage to the student) may be particularly important.

Opportunities for Mutual Adaptation

At the top of Table 4, opportunities for adaptation added 1% to 3% to the variance explained in computer usage (controlling for all previously reported effects). Most important, teachers reported more use of computers when they had explored new technologies on their own. This exploration likely enabled teachers to better understand the value of technologies and to develop the ability to use them, thus reducing the perceived costs of using technology. It could also be that teachers changed their pedagogical beliefs and practices and thus saw more benefit in certain uses of the computer. Moreover, this finding goes beyond the cognitive effects of the standard diffusion literature. Here again, the ecosystem metaphor applies, suggesting that the more contact two species have with one another the more they adapt to each other. Note that reading professional journals and seeking help from others also had borderline (in terms of statistical significance) relationships with student use of computers.

Other Factors

We left a few factors in the model to establish that they were not associated with use of computers, *once controls were in place for other characteristics.* Those factors were the perceived complexity of computers, the perceived relative advantage of computers for students, help from people who were not close colleagues, and attendance at district or school in-service trainings. We needed to control for perceived complexity before interpreting the association between help received and computer use. The reason is that some teachers are high users but receive little help because they perceive computers as not complex or not difficult to use. Indeed, the coefficients for help received increased when we controlled for expertise of the teacher. The fact that perceived relative advantage for students had negative (or zero) coefficients emphasizes the rational nature of teachers' decisions, which depended most directly on their own uses and needs (note that perceived relative advantage for students had larger coefficients before we controlled for perceived relative advantage for teachers). It is also important to establish that help from people other than close colleagues had essentially no relationship with reported use, whereas help from colleagues was highly related to student use of computers (the coefficients were different by more than 2 standard errors). Thus it appears that help is more important when the provider and receiver share an immediacy in the ecosystem. Finally, we retained attendance at district and school in-services because these are the most commonly used tools for increasing technology use, although they had little effect in our model.

Summary

Factors designating the ecosystem, the teacher's niche in the ecosystem, teacher–ecosystem interaction, teacher–computer predisposition for compatibility, and opportunities for mutual adaptation each had unique and important relationships with reported uses of computers. Moreover, the ecosystem metaphor offered a subtle distinction between sets of relationships. Specifically, teacher–computer predisposition for compatibility was more important for teacher uses of computers; teacher–ecosystem interactions were more important for student use of computers (with the exception of perceived pressure to use computers, which may have operated as much on predisposition for compatibility as directly on computer use).[6] Thus teachers were more responsive to the subsystem in engaging in behaviors that positioned the general resource of the subsystem—the students—for success. In contrast, when teachers considered their own behavior, their personal predispositions were most important. These complementary findings emphasize how teachers related to new technology in their ecosystem both as individual organisms and as members of a social system.

Discussion

The primary purpose of this study was to develop and test a framework from an ecological perspective to capture the organic process of technology uses in schools. Our key findings are depicted in Figure 2, by means of three pictures that illustrate the progressive (evolutionary) phases of technology adoption. (This is not to suggest that there are only three stages in the process. We view the process as ongoing; each picture can be viewed as representing a moment in time, continuous with the past and the future.) In the first phase, the district (on the left) provides the computer hardware, establishing the presence of the technology. This action is shown as passing through the barrier of the school, because in our data any variation in technology associated with schools can be attributed to districts. District in-service training, which attempted to mediate between teachers and technologies, is shown as barely entering the school (at top), on the basis of our empirical findings. In other words, district training does not yet seem to have had a significant impact on technology uses in schools, although it could become a significant factor at a later stage.

When a new technology is introduced into a school, other forces enter the school. External social and political institutions penetrate the school walls, as indicated by the waves in the upper left and lower right corners. New pedagogies enter at right through a permeable membrane, representing the need for a receptive teacher. These forces can potentially be absorbed and transmitted through collegial ties within the school, as shown by the solid lines between stick figures. Or teachers (existing species) may be uncertain about the value of the new technology, as indicated by the question mark over the head of one stick figure, or may reject it. Similarly, when exotic species enter an ecosystem such as the Great Lakes, some survive; most do not.

At the center of each phase in Figure 2 is the interaction between a focal teacher and the new technology. Initially, the technology has certain capabilities, represented by its shape as depicted. The teacher's perception of the value of the technology may reflect his or her history, pedagogical practices, and so forth, and may include an assessment of the costs associated with use. In the second phase, the teacher and the technology change shapes as they co-evolve. Note that the teacher's modifications are influenced by the help received and by perceived pressure from others (shown by the dotted lines). The other teachers may, themselves, be reacting to institutions or other forces exogenous to the school. This process is analogous to the settlement process of an invading species as it interacts with native species, which in relation to the invader may become food sources, competitors, or predators. The compatibility between the invading species and the native species influences their ability to survive. When new computer uses "invade" a school, the forces of the larger ecosystem are conveyed by relationships within the subsystem of the school.

In the last phase depicted in Figure 2, the technology begins to conform to the teacher, as teachers develop the capacity to modify software and hard-

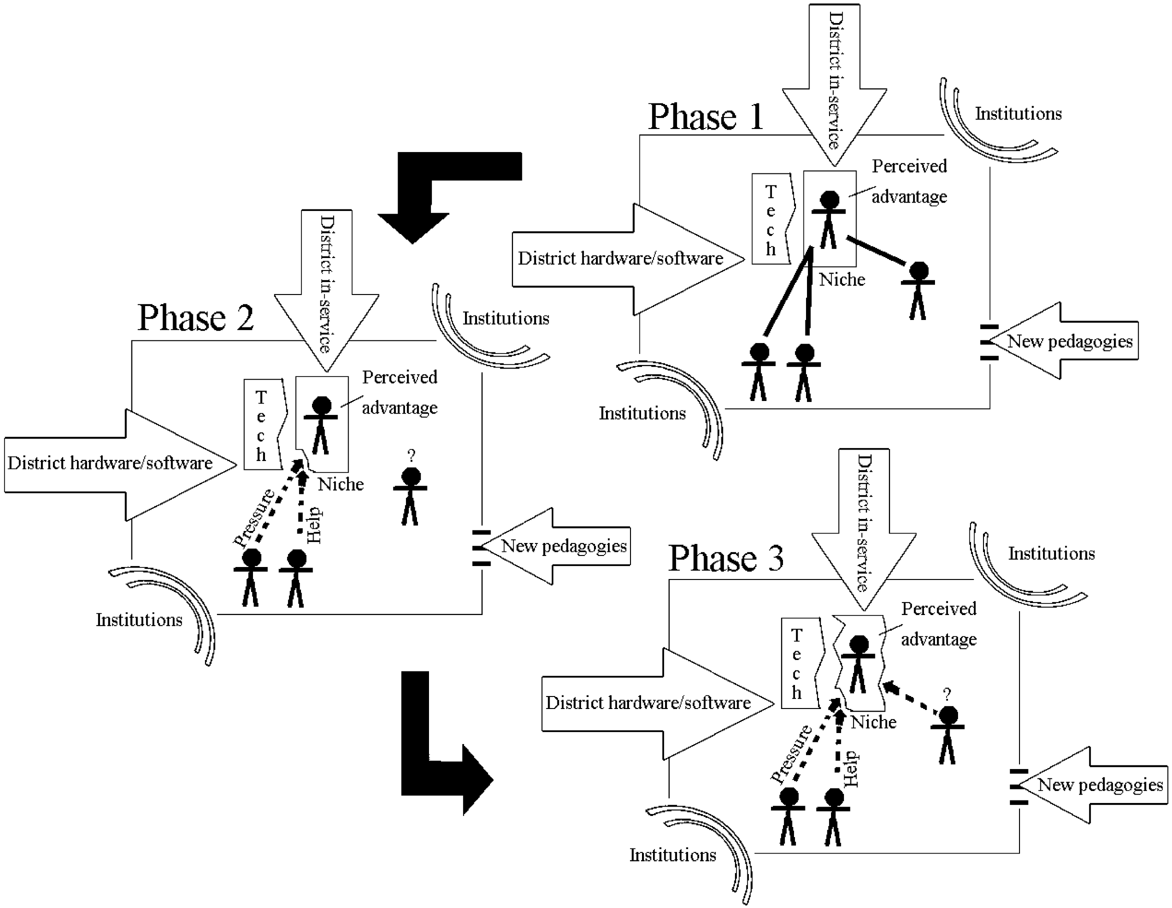

Figure 2. **The interactive process of technology adoption in schools. (Tech = new computer technology.)**

ware to suit their needs. At the same time, the teacher can also change her ways of interacting with the computer, which may demand different teaching practices. This is the stage of co-evolution, in which the invading species and the native species adapt to each other by changing themselves. In other words, the teacher may change her role to become more of a facilitator than an instructor, while the computer becomes a tool to support that. Or the teacher may find the intended uses of the computer completely incompatible and stop using it. In a very unlikely scenario, the computer uses could become so pervasive that the teacher's role in the school is transformed and her old role becomes extinct.

The focal teacher also continues to change shape as she interacts with the teachers who were first exposed to the new curriculum or other innovations (dashed lines). This change can make the focal teacher less compatible with the new technology, thus showing how multiple innovations can compete with each other. In the ecological metaphor, this happens when multiple exotic species invade an ecosystem, which forces the native species to adapt to all of them. The phases in Figure 2 show how multiple forces outside the school can affect the co-evolution of teacher and technology within the teaching ecosystem.

We wish to emphasize that many of the components that affect technology inhere in informal spaces of the school—the social aspects that are also a key point of departure for our ecological metaphor. In particular, the informal help and information that teachers provide to each other have important associations with computer use that are comparable to those of more commonly recognized factors. The informal social pressure that teachers exert on one another can also have a moderate effect on use. Finally, the play and experimentation that teachers engage in during breaks in the school day and outside the school context are critical to technology implementation. This finding strongly supports the fundamental concept of the ecological metaphor: that mutual adaptation between species, especially between existing and new species, requires frequent contact and active interactions at a local level.

Ultimately, the informal social organization of the school filters many of the factors that affect technology use. Continuing the ecological metaphor, teachers' immediate local ecology plays a vital role in shaping their reactions to technology, the alien species. Through informal interactions within the local ecology, teachers make sense of external opinions and information and exert pressure on one another to conform to internal norms. In other words, what matters most for teachers is their peers in the local environment.

The patterns of these informal processes are probably unique to a school's collegial structure. For example, in our findings, teachers were strongly influenced by help from colleagues. Thus teachers who have different colleagues will have different help resources, likely resulting in different levels or types of technology use. Therefore, the distribution of technology implementation is very much a function of the distribution of social relations within the school. Viewed from the ecological perspective, the dynamics within the local ecology affect the interactions of existing species with new ones.

Implications for Future Research

The ecological model suggests several directions for future research. First, it implies that, because the process of technology adoption is one of coevolution, a factor may play different roles at different times. Therefore, future research should include schools that are at different stages of technology adoption. Second, the ecological model draws special attention to teachers' rational calculation of the costs and benefits of adopting technology. Their calculation is based on perception rather than "reality." It would thus be fruitful to investigate the influences on teachers' perceptions and how those perceptions, and the reality, can be changed most efficiently. Third, this model highlights the vital role of local context in filtering external resources, opinions, and innovations. It would be beneficial to further explore the internal social dynamics among "existing species" and "new species" in schools that adopt new technologies. Fourth, the ecological model could be used to study the characteristics of the more desirable uses of the computer in schools and to determine under what conditions they may survive. Future research could specifically investigate the interactions between various types of uses for students and their interactions with the teaching ecosystem. Finally, the ecosystem model stresses dynamic interactions whereby species adapt to one another within the system. Such interactions drive coevolution. In other words, while the invading species, like the zebra mussel, may need to adapt to the ecosystem it enters, it can also change the ecosystem and its native species. Thus, as certain uses of computers are adopted by teachers, it will be important to study their effects on the school and teachers and to see what is replaced, what is changed, and what is maintained.

Implications for Policy and Practice

In discussing policy implications we note two important caveats. First, our sample is not entirely representative of the state in which the study was conducted. The schools that we studied were moderately more advantaged than the average elementary school in the state. (Nevertheless, the study may provide a glimpse into the near future for other schools that will soon invest in technology.) And our sampled schools come from only four districts; thus we have very little information about a key source of variation—the district. Second, we analyzed cross-sectional data. Thus we know many factors that are correlated with computer use, but any causal inferences are weak, and any statement we make about policy implications should be cautious.

Teacher-level Change

In our study, most of the variation in computer use was within schools. Therefore, in considering how to promote change in patterns of computer use in schools, we must focus on teacher-level factors. We found that those factors mapped onto four basic mechanisms for change: (a) recruitment/selection,

(b) training/socialization, (c) providing opportunities to explore and learn, and (d) leveraging change through the social context.

Recruitment/selection. Teacher job locations such as grade and subject and the extent to which computers complement the teaching style of a particular teacher are important predictors of computer usage, but the most likely mechanisms for effecting change in this category are attrition and recruitment/selection. The clear policy implication is to consider during the hiring process how adaptable a teacher will be to computer technologies.

Training/socialization. Change agents can provide training opportunities such as in-service and professional development conferences. But our evidence suggests that these activities may have little effect on computer use in the classroom for most teachers. It is more likely that teachers are socialized by other teachers to change their beliefs regarding the value of computer technology.

Providing opportunities to explore and learn. Change agents can provide various opportunities for teachers to explore and learn about new technologies. These opportunities have surprisingly strong effects on both teacher and student use of computers. Thus it seems that districts would do well to simply allow teachers release time to engage technology and consider its applications in their specific contexts.

Leveraging change through the social context. By giving teachers opportunities to help one another and to interact, schools may be able to increase the overall level of technology use. But leveraging change through the social context is a double-edged sword. If help is most important when coming from a colleague, it follows that teachers with few computer-savvy colleagues may not be able to access the kind of help they need to make fuller use of computers. Also, social pressure can be as strong a force working against technology as in favor of it. Change agents should be highly aware of the social structures and the school cultures in which they operate and should deliberately address shortcomings and pitfalls. This recommendation is also consistent with the finding that teachers are less likely to adopt new computer uses when they are asked to implement many other new practices. Before attempting to implement innovations, change agents should be aware of possible stress in relation to other innovations in the school culture.

Programmatic Possibilities

Our findings suggest several programmatic possibilities. First, instead of spending time and money on in-service programs and conferences, districts could provide teachers with opportunities to explore computer applications. Second, teachers could be given time to help one another. Thus individualized release time for exploration may not be as helpful as group-oriented activities such as a technology play-day, including district support but with ample opportunity for teachers to help one another. Third, schools should limit the number of innovations that they attempt and should devote ample resources to those they choose. Schools that try to adopt multiple innovations simultaneously may find that none are fully implemented.

Each of these policies taken separately is borne out by the data. But they become integrated under the ecosystem metaphor. In particular, the metaphor makes us aware that innovations are introduced into, and must take account of, systems and subsystems that are like small ecosystems. Thus change agents must take into account the extent to which organisms in an ecosystem are prepared to accommodate change; they must allow opportunities for mutual adaptation; they must allow for adaptation through the social processes of the system; and they must not overburden the system.

Conclusions

Although the ecological metaphor seems to be a powerful and useful analytical tool for understanding why computers are unused, underused, or misused in schools, we want to caution that a metaphor, by definition, is merely a rhetorical and conceptual device. We do not yet know exactly the limits of the metaphor, but we hope that our readers will not attempt to impose all theories and practices related to biological ecology on the human social system. That said, the ecological metaphor indeed helped us to better understand computer uses in schools. What we learned from the zebra mussel proved to be useful for interpreting the fortunes of its less successful counterpart, computer use in schools. The ecological model took us beyond simply identifying and correlating factors and focused our attention on interactions, activities, processes, and practices. If we accept the ecological metaphor, it becomes clear that innovations cannot be implemented without regard to the internal social structures of schools or other pressures that schools face. Thus we suggest an *evolutionary* rather than *revolutionary* approach to change in school computer use.

APPENDIX

Variables in the Model

Using the ecosystem metaphor, we organize our factors into the following types: the ecosystem, the teacher's niche in the ecosystem, teacher–ecosystem interaction, teacher–computer predisposition for compatibility, and opportunities for mutual adaptation. The factors included in this study were selected from two bodies of literature: (a) research on technology uses in schools, and (b) research on the diffusion of innovations. In this appendix we indicate factors described in the diffusion literature (e.g., Tornatzky & Fleischer, 1990; Wolfe, 1994) with an asterisk (*). Items marked with the pound sign (#) are those found to be strongest general predictors of diffusion by Tornatzky & Klein (1982). All measures are based on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree" unless otherwise specified.

The Ecosystem

We included three dummy variables to differentiate the four districts from which our teachers were selected.

The Teacher's Niche in the Ecosystem

The teacher's niche was measured by sets of dummy variables for subjects taught and a single term indicating grade level. We also included dummy variables to indicate teachers who had taught multiple grades and whose grade was unknown. The teacher's niche can be considered a component of the ecosystem, but because of its potential explanatory power, we list it as a separate category.

Teacher–Ecosystem Interaction

Help Received From Colleagues

We developed a measure based on the total amount of help that each teacher received from others. Social capital theory suggests that what matters is not just the amount of help received but the resource provided through that help (Coleman, 1988; Lin, 2001; Portes, 1998). In this case, the resource provided depends on the expertise of the provider. Expertise could not be independently measured by teachers' use of technology at a time prior to the provision of help; therefore, it could not be used as part of an independent variable predicting the use of help (Marsden & Friedkin, 1994). As a proxy for expertise, we measured how much each teacher provided help to others, reasoning that the more a person was called upon and able to help others, the more expert she was. Thus our measure of social capital was based on the amount of help that teachers received, weighted by the extent to which the providers generally helped others.

Ultimately we developed two measures of help: that received from close colleagues and that received from others who were not listed as close colleagues. The differentiation was based on whether a teacher listed the help provider as a close colleague or not. We made this distinction because the application of help may be highly contextualized. Thus the value of help may be highly dependent on the extent of the relationship and knowledge shared by the provider and the receiver, as distinguished by whether or not the provider and receiver are close colleagues. This differentiation may help to clarify whom teachers perceive as members of their own species or group, as suggested by the theory of reciprocal altruism.

Pressure to Use Computers

We also argue that an actor who exerts pressure draws on social capital by using the threat of detachment or ostracization to direct another's behavior. Correspondingly, organisms that wish to preserve their standing in a group conform to peer pressure. We measured social pressure through two teacher questionnaire items (correlated at .26): *Using computers helps a teacher advance his/her position in this school;* and *Others in this school expect me to use computers.*

Presence of Competing Innovations

In the ecological metaphor, multiple invading species may compete for resources, and ecosystems may therefore be limited in their capacity to accommodate multiple changes. The presence of competing innovations was measured with one questionnaire item: *We introduce many new things in this school.*

** Playfulness*

A potential user is more likely to identify valuable computer uses if he or she has opportunities to interact with the innovation without having to produce immediate products or results (Agarwal & Prasad, 1997). Playfulness is characterized here as an interaction between teacher (species), technology (species), and district (ecosystem), based on the frequency of teachers' opportunities to experiment with district-supported software, as reported by teachers (*Never* = 0, *Yearly* = 1, *Monthly* = 2, *Weekly* = 3, *Daily* = 4).

Location of Exposure

Some indigenous species are more exposed than others to invaders by virtue of their location in the ecosystem. Location of exposure is operationalized in terms of frequency with which teachers attended district or school in-service training programs for new technologies (*Never* = 0, *Yearly* = 1, *Monthly* = 2, *Weekly* = 3, *Daily* = 4).

Teacher–Computer Predisposition to Compatibility

In the ecosystem metaphor, how new species fit with existing species is essential to the survival of the new species. When technology uses are the new species, it is important to understand the fit, or compatibility, between computer uses and teachers.

**# Perceived Compatibility*

Potential users are more likely to implement technology that is consistent with their own existing values, past experiences, and needs (Tornatzky & Klein, 1982). "Compatibility" is similar to "magnitude" (Beyer & Trice, 1978) and "disruptiveness" (Zaltman, Duncan, & Holbek, 1973) in the sense that highly compatible innovations do not require large displacements in "organizational states." In the ecosystem metaphor, the degree to which computers are disruptive reflects the inherent compatibility of the two species, teachers and computer uses. Two compatible species tend to have fewer negative interactions, or at least to have commensal, if not mutualistic, interactions. We measured compatibility with the following four questionnaire items (alpha of .74): *Computers support what I try to do in the classroom; Computers distract students from learning what is essential; Computers are flexible;* and *It is easy to integrate computers with my teaching style.*

**# Perceived Complexity*

Potential users are less likely to implement a technology that they perceive to be complex to use (Tornatzky & Klein, 1982). "Perceived complexity" is similar to "ease of use" (Davis, 1989; Igbaria & Iivari, 1995; Mumford & Gustafson, 1988), "self-efficacy," and "uncertainty" (Zaltman et al., 1973). In the ecological metaphor, perceived complexity reflects the energy required for adaptation and thus the costs associated with using a technology. We measured it with a single item based how much of the time a teacher was able to solve technical problems on her own, described in a percentage.

**# Perceived Relative Advantage*

Potential users are more likely to implement technology that they believe gives them an advantage relative to the technology that it supersedes (Rogers, 1995; Tornatzky & Klein, 1982; Zaltman et al., 1973). "Perceived relative advantage" is similar to "centrality"—the degree to which an innovation concerns the major day-to-day work of the organization and involves activities critical to organizational performance (Nord & Tucker, 1987). It is also similar to "pervasiveness" and "scope" (Beyer & Trice, 1978; Zaltman et al.) and "perceived usefulness" (Davis, 1989; Hage, 1999; Igbaria & Iivari, 1995). In the ecosystem metaphor, this variable is the perceived advantage to teachers as rational actors in a competitive environment. It was measured with two sets of items for (a) the perception that computers can help teachers (alpha = .92) to integrate various aspects of the curriculum, teach innovatively, direct student learning, model an idea or activity, connect the curriculum to real-world tasks, and be more productive; and (b) the perception that computers can help students (alpha = .89) to think critically, gather and organize information, explore a topic, be more creative, be more productive, and develop new ways of thinking.

Opportunities for Mutual Adaptation (Teacher Professional Development)

Given our ecosystem metaphor, we view professional development as providing opportunities for co-evolution and mutual adaptation between species. We found it interesting, however, that no subset of the mechanisms for adaptation (e.g., the forms of professional development) formed a reliable scale. Perhaps in this context teachers view multiple mechanisms for adaptation as redundant and thus as mutually exclusive activities. Consequently, we explored effects of the following items separately: *Seek help from others to learn about new technologies; Read professional journals about new technologies;* and *Explore new technologies on my own* (*Never* = 0, *Yearly* = 1, *Monthly* = 2, *Weekly* = 3, *Daily* = 4).

Notes

This study was made possible by a grant from the Michigan Department of Education, but the views and findings expressed here do not necessarily reflect the views or positions of the department. In addition to the authors, the following individuals participated in the design and implementation of the study: Blaine Morrow, Kathryn Hershey, Joe Byers, Nicole Ellefson, Susan Porter, Rick Banghart, Andrew Henry, and Nancy Hewat. Although we cannot identify the 19 schools that participated in this study, we want to thank all of the teachers and administrators in those schools. Without their cooperation and support, this study would not have been possible. We would also like to thank Maenette K. P. Benham, Ronald H. Heck, and the four anonymous reviewers for their insightful comments. Mary Bremigan, Ann Krause, Punya Mishra, Matthew Koehler, Patricia Soranno, and Gary Cziko offered very helpful comments and suggestions. In addition, we thank Anne-Marie Cziko for directing us to the information about ants.

[1]Bruce and Hogan (1998) analyze technology and literacy from an ecological perspective. Nardi and O'Day (1999) refer to settings where technology is used as "information ecologies," which are systems of "people, practices, values, and technologies in a particular local environment" (p. 49).

[2]Various insect species have been found to take suicidal actions to defend their colonies—displaying altruism in which individuality is sacrificed for the sake of the collective (Anderson & McShea, 2001; Wright, 1994). One of the most fascinating "selfless" fighters is the Camponotus *(saundersi)* ants found in Southeast Asia. Genetically programmed to be "walking bombs" (Oster & Wilson, 1978, p. 226), these ants literally explode in front of their attackers. This is accomplished by muscular contractions around an overdeveloped mandibular gland filled with toxic secretions. Faced with enemies or predators, they contract their abdominal muscles violently, bursting open the body wall and spraying the secretions into the foe (Hölldobler & Wilson, 1990).

[3]Defining social capital as the potential to access resources through social relations (Coleman, 1988); for recent reviews see Lin, 2001; Portes, 1998; Frank, Zhao, and Borman (in press) argue that an actor who receives help that is not formally mandated draws on social capital by obtaining information or resources through social obligation or affinity. Thus the ecosystem metaphor integrates social capital through sociobiology; members of

a species perpetuate their genes by supporting each other or share resources, driven by reciprocal altruism. Teachers invest in each other because of their shared interest in students or because they realize that they all need help sometimes (Frank, 2002).

[4]In the same way that biological evolution takes place through mechanisms of natural selection of genes or groups of genes, cultural evolution takes place through variation and retention of the *memes*.

[5]Our theoretical model stipulates that teachers are affected by societal institutions and are nested within federal, state, district, and school contexts. But because the teachers in our sample came from a single state, they were exposed to common state (and federal) policies, as well as common societal institutions. Therefore, we did not include characteristics of state and federal policy and societal institutions in our regression model. Because we had only four districts, we accounted for districts by using fixed effects (i.e., three dummy variables). Once districts were accounted for, schools accounted for less than 0.1% of the overall variation (this finding was established with multilevel models that apportioned the variation among teachers, schools, and districts). Thus schools need not be included in our final model. Finally, the effects of subcontexts within schools were measured in terms of general relationships between the teacher and the system, such as the teacher's perception of pressure to use computers and the teacher's unique access to expert colleagues, measured by using network data. Thus, ultimately, we could estimate our models as single-level regressions, including districts as ecosystems, by using fixed effects and teacher-system interactions as characteristics of the teacher.

[6]Although the pairs of coefficients for teacher–computer predisposition for compatibility and teacher–ecosystem interaction are not statistically different in general (see Cohen & Cohen, 1983, p. 111, for the test between two coefficients), as a set they support an interesting and valuable interpretation.

References

Agarwal, R., & Prasad, J. (1997). The role of innovation characteristics and perceived voluntariness in the acceptance of information technologies. *Decision Sciences, 28*(3), 557–582.

Anderson, C., & McShea, D. W. (2001). Individual versus social complexity, with particular reference to ant colonies. *Biological Reviews, 76*(2), 211–237.

Anderson, R. E., & Ronnkvist, A. (1999). *The presence of computers in American schools.* Irvine, CA: Center for Research on Information Technology and Organizations, University of California, Irvine. Available at *http://www.crito.uci.edu/tlc/findings/computers_in_american_schools*

Basalla, G. (1988). *The evolution of technology.* Cambridge, UK: Cambridge University Press.

Becker, H. J. (2000a). Findings from the teaching, learning, and computing survey: Is Larry Cuban right? *Education Policy Analysis Archives, 8*(51). Available at *http://epaa.asu.edu/epaa/v8n51/*

Becker, H. J. (2000b). Who's wired and who's not: Children's access to and use of computer technology. *The Future of Children, 10*(2), 44–75.

Becker, H. J. (2001, April). *How are teachers using computers in instruction?* Paper presented at the annual meeting of the American Educational Research Association, Seattle.

Beyer, J. M., & Trice, H. M. (1978). *Implementing change.* New York: Free Press.

Bromley, H. (1998). Data-driven democracy? Social assessment of educational computing [Introduction]. In H. Bromley & M. Apple (Eds.), *Education, technology, power* (pp. 1–28). Albany: State University of New York Press.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design.* Cambridge, MA: Harvard University Press.

Bronfenbrenner, U. (1995). Developmental ecology through space and time: A future perspective. In P. Moen, J. G. H. Elder, & K. Luscher (Eds.), *Examining lives in* *context: Perspectives on the ecology of human development* (pp. 619–647). Washington, DC: APA Books.

Bronfenbrenner, U., & Ceci, S. J. (1994). Nature-nurture reconceptualized: A bioecological model. *Psychological Review, 101*(4), 568–586.

Bronfenbrenner, U., & Morris, P. A. (1998). The ecology of developmental processes. In R. M. Lerner (Ed.), *Theory: Vol. 1. Handbook of child psychology*. New York: Wiley.

Bruce, B. C. (1993). Innovation and social change. In B. C. Bruce, J. K. Peyton, & T. Batson (Eds.), *Network-based classrooms* (pp. 9–32). Cambridge, UK: Cambridge University Press.

Bruce, B. C., & Hogan, M. P. (1998). The disappearance of technology: Toward an ecological model of literacy. In D. Reinking, M. C. McKenna, L. D. Labbo, & R. D. Kieffer (Eds.), *Handbook of literacy and technology: Transformations in a post-typographic world* (pp. 269–281). Mahwah, NJ: Erlbaum.

Cattagni, A., & Farris, E. (2001). *Internet access in U.S. public schools and classrooms: 1994–2000*. Washington, DC: National Center for Education Statistics.

Cohen, D. K. (1987). Educational technology, policy, and practice. *Educational Evaluation and Policy Analysis, 9*(2), 153–170.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology, 94,* 95–120.

Collins, A. (1996). Whither technology and schools? Collected thoughts on the last and next quarter centuries. In C. Fisher, D. C. Dwyer, & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 51–66). San Francisco: Jossey-Bass.

Cuban, L. (1986). *Teachers and machines: The classroom uses of technology since 1920*. New York: Teachers College Press.

Cuban, L. (1999, August 4). The technology puzzle: Why is greater access not translating into better classroom use? *Education Week, 68,* 47.

Cuban, L. (2001). *Oversold and underused: Computers in schools, 1980–2000*. Cambridge, MA: Harvard University Press.

Cziko, G. A. (1995). *Without miracles: Universal selection theory and the second Darwinian revolution*. Cambridge, MA: MIT Press.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

Dawkins, R. (1989). *The selfish gene*. Oxford, UK: Oxford University Press.

Frank, K. A. (2002). *The dynamics of social capital*. Paper presented at the annual meeting of the International Social Networks Association, New Orleans.

Frank, K. A., Zhao, Y., & Borman, K. (in press). Social capital and the implementation of computers in schools. *Journal of Sociology of Education*.

Hadley, M., & Sheingold, K. (1993, May). Commonalities and distinctive patterns in teachers' integration of computers. *American Journal of Education, 101,* 261–315.

Hage, J. T. (1999). Organizational innovation and organizational change. *Annual Review of Sociology, 25,* 597–622.

Hodas, S. (1993). Technology refusal and the organizational culture of schools. *Educational Policy Analysis Archives, 1*(10). Available at *http://epaa.asu.edu/epaa/v1n10.html*

Hölldobler, B., & Wilson, E. O. (1990). *The Ants*. Cambridge, MA: Harvard University Press.

Igbaria, M., & Iivari, J. (1995). The effects of self-efficacy on computer usage. *Omega International Journal of Management Science, 23*(6), 587–605.

Lemke, J. L. (1994). Discourse, dynamics, and social change. *Cultural Dynamics, 6*(1), 243–275.

Levinson, P. (1997). *The soft edge: A natural history and future of the information revolution*. New York: Routledge.

Lin, N. (2001). *Social capital: A theory of social structure and action*. New York: Cambridge University Press.

Lortie, D. (1975). *Schoolteacher*. Chicago: University of Chicago Press.

Louis, K. S., Toole, J., & Hargreaves, A. (1999). Rethinking school improvement. In J. Murphy & K. S. Louis (Eds.), *Handbook of research on educational administration* (2nd ed.). San Francisco: Jossey-Bass.

Loveless, T. (1996). Why aren't computers used more in schools? *Educational Policy, 10*(4), 448–467.

Marsden, P., & Friedkin, N. E. (1994, August). Network studies of social influence. *Sociological Methods & Research, 22*(1), 127–151.

Mumford, M. D., & Gustafson, S. B. (1988). Creativity syndrome: Integration, application and innovation. *Psychological Bulletin, 103*(1), 27–43.

Nardi, B. A., & O'Day, V. L. (1999). *Information ecologies: Using technology with heart*. Cambridge, MA: MIT Press.

Nord, W. R., & Tucker, S. (1987). *Implementing routine and radical innovations*. Lexington, MA: Lexington Books.

Odum, E. P. (1997). *Ecology: A bridge between science and society*. Sunderland, MA: Sinauer Associates.

Oster, G. F., & Wilson, E. O. (1978). *Caste and ecology in the social insects*. Princeton, NJ: Princeton University Press.

Portes, A. (1998). Social capital: Its origins and applications in modern sociology. *Annual Review of Sociology, 24,* 1–24.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). New York: Free Press.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student-centered classrooms*. New York: Teachers College Press.

Schofield, J. W. (1995). *Computers and classroom culture*. New York: Cambridge University Press.

Shuter, B., & Mason, D. M. (2001). *Exotic invertebrates, food-web disruptions, and lost fish production: Understanding impacts of Dreissenid and Cladoceran invaders on lower-lakes fish communities and forecasting invasion impacts on upper-lakes fish communities* [White paper]. Ann Arbor, MI: Great Lakes Fishery Commission.

Simon, H. (1957). *Models of Man*. New York: Wiley.

Smerdon, B., Cronen, S., Lanahan, L., Anderson, J., Iannotti, N., & Angeles, J. (2000). *Teachers' tools for the 21st century: A report on teachers' use of technology*. Washington, DC: National Center for Education Statistics.

Tornatzky, L. G., & Fleischer, M. (1990). *The process of technological innovation*. Lexington, MA: Lexington Books.

Tornatzky, L. G., & Klein, K. J. (1982). Innovation characteristics and innovation adoption–implementation: A meta-analysis of findings. *IEEE Transactions on Engineering Management, 29,* 28–45.

Tyack, D. B., & Cuban, L. (1995). *Tinkering toward utopia: A century of public school reform*. Cambridge, MA: Harvard University Press.

Vanderploeg, H. A., Nalepa, T. F., Jude, D. J., Mills, E. L., Holeck, K. T., Liebig, J. R., et al. (2002). Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 59,* 1209–1228.

Wolfe, R. A. (1994). Organizational innovation: Review, critique and suggested research directions. *Journal of Management Studies, 31*(3), 405–431.

Wright, R. (1994). *The moral animal: The new science of evolutionary psychology.* New York: Vintage Books.

Zaltman, G., Duncan, R., & Holbek, J. (1973). *Innovations and organizations.* New York: Wiley.

Zhao, Y., & Conway, P. (1999, April 19–23). *What is for sale today? An analysis of state educational technology plans.* Paper presented at the annual meeting of the American Educational Research Association, Montreal.

Zhao, Y., & Cziko, G. A. (2001). Teacher adoption of technology: A perceptual control theory perspective. *Journal of Technology and Teacher Education, 9*(1), 5–30.

Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for classroom technology innovations. *Teachers College Record, 104*(3), 482–515.

Manuscript received August 15, 2002
Revision received September 3, 2002
Accepted November 5, 2002