FACTORS AFFECTING TECHNOLOGY USES IN SCHOOLS[1]:

AN ECOLOGICAL PERSPECTIVE

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Abstract

Why isn't technology used more in schools? Many researchers have been searching for solutions to this persistent puzzle. In this paper, we extend existing research on technology integration and diffusion of innovations by investigating relationships among the long list of factors that have already been identified to be related to school technology uses. In particular, we use the metaphor of an ecosystem to theoretically integrate and organize sets of factors that affect implementation of computer technology. We also hope that this metaphor will help us better understand other educational innovations. We conducted a study of technology uses in 19 schools in four districts. Findings of this study suggest that the ecological perspective can be a powerful analytical framework for understanding technology uses in schools. This perspective points out new directions for research and has significant policy and practical implications for implementing innovations to schools.

FACTORS AFFECTING TECHNOLOGY USES IN SCHOOLS: AN ECOLOGICAL PERSPECTIVE

> 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 wide spread of other alien species. In the last 15 years, the zebra mussel has greatly disrupted the fish communities in the Great Lakes(Shuter & Mason, 2001).

While scientists, policy makers, environmentalists, and the public have been concerned about the ecological and economical consequences of the very rapid dispersal of the zebra mussel in the Great Lakes, educational researchers and practitioners, policy makers, and the public have been equally concerned about the frustratingly slow adoption of computers and other modern technologies in schools. Like many educational reform efforts, the introduction of technology in schools has been less than successful. Over the last century there were several waves of massive investment in technology to improve education, but none has had significant lasting impact on education(Cuban, 1986). The most recent movement to put computers in schools has so far met the same fate as previous attempts. 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). The types of uses envisioned by techno-enthusiasts to revolutionize teaching and learning are rarely observed in the nation's schools(Becker, 2001; Cuban, 1999, 2001; Schofield, 1995).

The dispersal of Zebra mussels in the Great Lakes and computer uses in schools are of course quite different but they have one important thing in common: they were both outsiders, alien species, foreign objects to the environment they entered. The introduction, survival, and dispersal of an alien species in a new environment is a very complex process. To understand this process 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.

The ecological approach seems to have yielded fruitful results in understanding the successful invasion of the zebra mussels in the Great Lakes. Thus, in this article, we draw on ecological research on the invasion of exotic species such as the zebra mussel to develop a framework for understanding computer uses in schools. In the remainder of 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 upon the ecosystem metaphor. After that, we report an empirical study that applies the metaphor. Finally, we discuss the implications of the framework and the study for future research, policy, and practice.

The Need for a Unifying Framework

Concerns over the slow adoption of technology by teachers are not new. Many researchers have, from various angles, studied the phenomenon using different approaches, from case studies(Cuban, 2001; Schofield, 1995; Zhao, Pugh, Sheldon, & Byers, 2002), historical analysis(Cuban, 1986), to large surveys(Becker, 2000, 2001). These studies offer different accounts for why teachers do not frequently use technology to its full potential and in revolutionary ways that can truly lead to qualitatively different teaching and learning experiences.

Some researchers believe that schools, being the social organization they are, are directly at odds with new technologies. The goal of schools as 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 the existing practices (Cohen, 1987; Cuban, 1986). “What appears to outsiders as a straightforward improvement can, to an organization, be felt as undesirably disruptive if it means that culture must change its values and habits in order to implement it.” (Hodas, 1993, p. 2)

Besides this inherent resistance to change, schools are also said to have a structure that prevents wide spread uses of computers. Collins(1996) in his reflective essay on his experience with the Apple Classroom of Tomorrow (ACOT) 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(Cuban, 1986; Smerdon et al., 2000; US Congress Office of Technology Assessment, 1995). More serious problems, however, lie beyond technological or physical structures in the conceptual structure of schools.

> . . . the 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.)

In a similar view, Papert(1999) compares the current school to a 19th century stagecoach while new technologies to a jet engine. "When they try [attaching the jet engine to the stagecoach] they soon see that there is a danger that the engine would shake the vehicle to pieces. So they make sure that the power of the engine was kept down to a level at which it would not do any harm." Thus the structure of the school severely hampers the power of new technologies for learning (Means, 1994). The introduction of computers requires serious changes in the curriculum, teaching practices, reallocation of resources, and perhaps rearranging the fundamental structure of schools(Collins, 1996; Hawkins & Sheingold, 1986; Means, 1994; Merrow, 1995). Consequently schools and teachers may be less enthusiastic by the promises of the computer delivered than its advocates.

A more frequently cited set of factors affecting technology uses in schools is associated with the teacher. Following the standard diffusion literature (e.g., Rogers, 1995), teachers' attitudes toward and expertise with technology have often been identified as key factors associated with their uses of technology (Becker, 2000; Bromley, 1998; Hadley & Sheingold, 1993; Sandholtz, Ringstaff, & Dwyer, 1997; Smerdon et al., 2000; Zhao & Conway, 1999). Unless a teacher holds a positive attitude toward technology, it is not likely that she will use it in her teaching. Teacher's pedagogical beliefs and their teaching practices are also factors that seem to influence their uses of technology (Becker, 2000a, 2000b; Hadley & Sheingold, 1993; Sandholtz et al., 1997; Zhao & Cziko, 2001).

Technology itself has also been named as the source of a set of factors that affect its uses by teachers. 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 values of technology. Second, the constant changing nature of technology makes it difficult for teachers to stay current with the latest technology. Everyday new software and hardware becomes available. Teachers, who are already struggling for time and energy, find it difficult and discouraging to keep chasing this elusive beast. Third, the inherent nature of unreliability makes technology less appealing for most teachers(Cuban, 1999; Zhao et al., 2002). Technology is inherently unreliable and can break down at any time but teachers, who have only a limited amount of time in front of students, cannot spend the time troubleshooting problems they may or may not be able to solve. Thus unless there is a strong need for the use of technology and reliable support, teachers may opt not to use it in their teaching.

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 of each other or the system in which they interact with each other. Rarely are they studied together under a framework to sort out the relevant importance of these factors and identify the relationships among them. Moreover, we cannot seem to find a framework in the existing literature that captures the dynamic nature of the technology adoption process. In the quest to look for factors that affect technology uses, not much attention has been paid to develop an understanding of how the factors dynamically interact with each other and technology uses. That is, while we have come up with a list of what, we are short in the how. Consequently, research in this area is in desperate need of a framework that can help it move beyond simply verifying the correlation between teacher's technology competency and technology uses or identifying new factors to add to the "laundry list" of factors associated with technology uses. Finally, these factors are discussed in different terms; some cognitive, some social, some organizational, some technological, and still some psychological. To understand the process of technology adoption, we need one framework that allows us to talk about these factors in similar terms.

In order to understand why the zebra mussel so rapidly invaded the Great Lakes ecosystem, ecologists must understand the ecological conditions, including existing species, temperatures, and other geographical characteristics. Similarly in order to appreciate 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 Ecosystem Metaphor: Learning from Zebra Mussels

> The successful invasion of the zebra mussels in the Great Lakes has drawn much attention from 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 invasion process and patterns of the zebra mussels and several Ponton-Caspian endemics that have recently successfully invaded the Great Lakes, Vanderploeg et al. (2002) find that the zebra mussel is an *r* strategists (A reproductive strategy in which energy is invested in a multitude of offspring that receive little or no parental care.), who 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. In addition, the activity cycle of native unionid shells make it possible for zebra mussels to wipe them out. Moreover, the zebra mussels do not have any predators. Finally they benefit a great deal from human activities—ballast water transportation facilitates the dispersal of the zebra mussels.

Obviously, the successful invasion of the zebra mussels is a result of many factors working together. It is the compatibility between the life-history characteristics and environmental tolerance of the zebra mussel and the receiving environment—the Great Lakes ecosystem. It is the frequent arrival of the zebra mussels in sufficient quantity thanks to active trans-Atlantic shipping. Any missing link in this process may have resulted in a different ecological picture. In fact, most species do not survive when taken out of their native environment and placed in a new setting for this reason. Thus to accurately account for the success of zebra mussels' invasion and predict its impact, we need to take into consideration all these factors together. What enables us to do so is the emerging science of ecology, particularly the concept of ecosystem.

Because of its attention to both parts and wholes, both the actors in an environment and their dynamic interactions with each other as well as the environment, and both living and non-living things, the ecological approach seems to provide 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). Thus in the next few paragraphs we identify the components and characteristics of ecosystems that we will then apply to the processes of 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 placed an emphasis on 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 to arrange things into graded compartments. Ecosystem is the lowest level in the ecological hierarchy that 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. This 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 refers to it inorganic characteristics, while the biotic community of an ecosystem is composed of populations of organisms or species. A species must have a habitat—the place where the species live and a niche—the role 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.   While these dominants may be common, the rare species are also important. 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).

In order to conduct the analysis of technology uses in ecological terms, we need to first establish four metaphorical equivalents between the issue of technology uses in schools and ecological issues: a) classrooms as ecosystems; b) computer uses as living species; c) teachers as members of a keystone species; and d) external educational innovations as invasions of exotic species. These metaphorical bridges are expected to help us apply what we learn from examples such as the zebra mussel invasion to our current task of understanding technology uses in schools.

Schools as Ecosystems

Viewing human institutions as ecosystems is not new. Bronfenbrenner (1979; 1995; Bronfenbrenner & Ceci, 1994; Brofenbrenner & Morris, 1998) has long been a champion in developing theories and conducting research about human development from an ecological perspective. Lemke(1994) uses the term “ecosocial system” in his application of the ecological approach to the study of cultural change. Bruce and Hogan(1998) analyzed 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).

A teacher's teaching environment also can be viewed as an ecosystem much like the Great Lakes. It is a complex system of many parts and relationship, of both biotic (e.g., teachers, students, parents, administrators etc.) and abiotic components (e.g., physical setting, location of the computers, grades and subjects of teaching). 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 function over a long period of time in a hierarchy. It is nested in a school district, which in turn is a subset of a state educational system which is nested within a national education system. Just like in a bio-ecosystem, the teaching ecosystem exhibits plenty of diversity in that it has many different types of species, each of which has a different set of characteristics and plays a different role or occupies a unique niche in ecological terms. Their characteristics and roles affect one another continuously, constantly modifying their relationships with each other.

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 human activities such as computer uses as biological organisms. However, we believe this is a reasonable and logical interpretation of the metaphor. In fact, many scholars before us have made a similar stretch and proven it fruitful(Basalla, 1988; Cziko, 1995; Levinson, 1997; Popper, 1972) . For example, Dawkins(1989) made a convincing argument that "cultural transmission is analogous to genetic transmission in that, although basically conservative, it can give rise to a form of evolution." (p. 189). In the same way biological evolution takes place through mechanisms of natural selection of genes or groups of genes, cultural evolution takes place through the variation and retention of what Dawkins(1989) called memes, which are ideas. Memes, like genes, are "selfish." They compete for survival—genes in biological form and memes in cultural form.

Although technologies are not exactly the same as living creatures, they seem to follow the same process of evolution: diverse human needs, experiences, and talents lead to the development of a diversity of technologies, some of which are judged better by their users than others and they survive while others perish because they are judged to be less fit; new needs are discovered or brought about by these "fittest of the moment" technologies, so newer technologies are developed based on the existing ones; again some of the newer ones will be more fit than others and they survive and generate new variations(Basalla, 1988; Cziko, 1995; Levinson, 1997).

We propose to view computer uses, that is, the realization of computer functions, as biological species such as the zebra mussel. Today the computer is no longer a simple calculating machine. Instead it has many possible functions, which when realized in a particular setting can be expressed in a variety of uses. Moreover, the functions of the computer are constantly changing. New functions emerge from existing functions all the time. New uses are also proposed constantly. We propose to think that the diffusion of computer uses is subject to the same principle of "survival of the fittest" as their genetic and biological counterparts: some of the uses are more compatible than others with a given environment and thus more are more likely to survive.

Teachers as Individuals and Members of a Species

In an ecosystem, we observe constant species-to-species interactions like the ones between the zebra mussel and native mussels. While we consider the species-to-species interactions, we should not ignore the fact that individual members of a species also interact with each other. The within species interactions can take similar patterns as interactions between species. They can compete as well as cooperate with each other.

Although genes and biological organisms made up of genes are fundamentally "selfish," they can establish cooperative relationships or exert 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 as some ants detonate themselves to protect the colony(Wright, 1994). Different theories have been put forth to explain the rampant altruism observed among ostensibly selfish animals and human beings. One of the explanations is called reciprocal altruism(Dawkins, 1989; Wright, 1994), 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 primarily concernd with the well-being of their classroom (Lortie 1979). But they also live and work in social groups and know that they may need help from others some times. So following the principle of reciprocal altruism, we can expect they would help others as needed. Just as members of a clan help one another to perpetuate the gene line, teachers may help and respond to members of their common organization, the school, to perpetuate the well being of the school(Frank, Zhao, Borman, submitted). This reciprocal altruism enables selfish beings to work together, to give and collect help, to build "social capital."

Teachers draw on help from others in their schools and districts to implement computers. Defining social capital as the potential to access resources through social relations (Coleman 1988; Putnam 1993; see Lin 2001, Portes 1998, or Woolcock 1998, for recent reviews), Frank, Zhao , & Borman(2002) 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 members of their clan or share resources driven by reciprocal altruism. That is, teachers invest in each other because of their shared interests in common students or because of their realization that they all need help some day(Frank, 2002).

External Innovation as Invasion

The last metaphorical bridge we want to build likens innovations to ecological invasions of an ecosystem by foreign species. As mentioned before, an ecosystem has the tendency or ability to maintain internal equilibrium. The introduction of new species, intentional or unintentional, to varying degrees affects this equilibrium. When a new species, such as the zebra mussel, enters an existing ecosystem (e.g., the Great Lakes), it essentially is an invader from outside. The invading species may have interactions with one or more existing species. Depending upon the properties of the invader and the existing species as well as 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 due to its limited capacity; c) the invader loses and perishes; and d) both go through a process of variation and selection and acquire new properties.

Computer uses promoted by techno-enthusiasts to schools are invading species, just like zebra mussels came to the Great Lakes with ships. Whether they can be successfully adopted and become a permanently established depends on their compatibility with the teaching environment, including the teachers and other species in the same way the success or failure of the zebra mussel invasion is determined.

Interaction within the Teaching Ecosystem

Thus far we have proposed four metaphorical connections between technology uses in schools and the ecology of the natural world: 1)schools as ecosystems; 2)computer uses as species; 3)teachers as individuals and members of a species; and 4)innovation as invasion. We now turn to the development of a framework for understanding technology uses in schools from an ecological perspective. In this framework, we treat the frequency and types of computer use by teachers as indicators of well-being of the computer-species in the classroom ecosystem. There are two main types of uses in terms of the purposes of use: a) for students and b) for teachers. Teachers may apply technology for their own professional use (e.g., to develop materials) but not their students (e.g., for student presentations), or vice versa. This distinction aligns with our application of the ecosystem 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, this distinction between teacher and student uses and benefits is not pure. For example, when teachers gain efficiency through their own use this may improve learning and have immediate systemic benefits, or when teachers facilitate student use this may have immediate benefit on classroom management. Each type is considered an individual species; uses for student benefit all in the school, whereas those for teacher benefit the individual teacher. How often the computer is used for each purpose can be considered the size of the population of each species.

Qualities of the Invading Species and Characteristics of Computer Uses

There are two sets of factors that affect the population or well-being of the invading species in terms of sources: a) qualities of the species and b) interactions with existing species and the ecosystem environment. Dawkins (1989) suggests that more successful genes or memes have three qualities: longevity, fecundity, and copy-fidelity. 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.

Fecundity, for genes, means it makes copies faster, while for memes, propagates faster. In other words, technology uses that have fecundity can reach more people in a short period of time. Thus in our case, the types of uses that are exposed to more teachers are more likely to endure. Furthermore, an ecosystem that enhances the fecundity of a particular gene provides that gene more opportunity to be successful. Similarly in schools where teachers have more opportunity to work together with computers may see computers used more.

Dawkins' third quality of more successful genes, copy fidelity, seems less applicable to memes or cultural artifacts because as an idea passes from one person to another, it often changes or mutates and blends. But Dawkins provided a forceful argument that in fact genes seem to blend into large "gene complexes" as well. Since a meme can be large or small, even when it seems to mutate or blend with other memes, it still survies, just in a large unit. Copy fidelity, or accuracy of copies, seems to work against survival in the evolutionary process, which looks for variation—errant copies of the original. Again, Dawkins argues that even though evolution seems to be a "good" thing, "nothing actually 'wants' to evolve." (p. 18). Evolution just happens in spite of the effort of the genes or memes to prevent it. In other words, memes and genes want to make exact copies of themselves. This is the same for ideas about computer uses or innovations—innovators often want them to be implemented faithfully by others, although most of them are keenly aware that changes are often inevitable (Tornatzky and Fleischer, 1990).

Interacting with the Environment and the Role of the Teaching Ecosystem

The survival of the invading species is determined not only by its own life-history characteristics, but also by the compatibility of these characteristics with the new environment, in the case of computers in schools, that environment is the teacher's teaching context. Considered an ecosystem, the teacher's teaching context is nested in a larger multi-level ecological hierarchy. We begin with the government levels and societal institutions at the top of the hierarchy. As documented in the introduction, there is strong institutional demand at the societal level to place computers in classrooms, even if there is debate about the educational value of computers. States and the federal government can support hardware and connectivity, as well as provide small amounts of training. To a certain degree, the larger context seems favorable for computer uses. However, although they undoubtedly affect teachers' technology use, societal institutions and federal and state policies are remote from any given teacher's classroom experience. As such they can be thought of as geological forces that shape the general landscapes that teachers inhabit as professionals. In the example of the zebra mussels, these are more like the sun, which provides the vital energy to the Great Lakes ecosystem but remote from the zebra mussels.

The more immediate ecosystem with which computer uses need to be compatible is defined by the school district, which can support hardware and software and is more likely responsible for training and opportunities to learn. Thus if the school district provides sufficient resources to support computer uses, computer uses are likely to spread more quickly.

Schools and their social contexts shape the local and most immediate ecosystem wherein computers are used. With respect to technology, it is schools that provide release time giving teachers opportunities to engage technology, and it is other teachers who can exert pressure to use computers or who can provide contextualized information about the value and implementation of technology. 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, availability of computer hardware and software), scheduling, and physical layout of the building, and subjects and grades teachers teach make up the abiotic component of the school ecosystem, which influence the types and frequencies of uses. For example, some subject matters and grades are more conducive to certain types of computer uses. Technology education, computer education, and business are subjects that have unfilled niches for one type of computer uses (teaching technology as the subject content), while special education courses provide the opportunity for drill-and-practice type of uses. 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 uses of other teaching and learning tools (e..g, books, copying machines, phones etc) make up the bioctic component. Computer uses may compete for resources with any one of these species. A simple example is 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 the traditional library. A more interesting and complex example is when computers are used to support student-centered project-based learning, as envisioned by many constructvist proponents of computers, they compete with some teachers, especially those who espouse a traditional teacher-centered approach. Such uses may also be incompatible with the need to prepare students for standardized tests.

Interacting with Keystone Species and Teachers' Cost-benefit Analysis

In its final analysis, the survival of computer uses is determined largely by its compatibility with teachers, the keystone species in the ecosystem. We view teachers as purposeful and rational decision makers who, in the face of an innovation, behave in ways similar to any species in an ecology facing the introduction of a new species. However this is not to suggest that teachers actually pull out a spreadsheet and compute the costs and benefits of a certain way to use the computer. Nor is it the case that teachers' decisions are based on complete information and necessarily optimal in terms of educational value. In fact, very often, we would argue teachers make decisions based on limited information and in response to pressure. Nonetheless, a teacher's decision is based on the calculation of costs and benefits, although that calculation may be quick and appear impulsive(Zhao & Cziko, 2001).

Traditionally benefits of technology uses have often been interpreted in terms of student achievement while the benefits and costs can in fact be in a variety of forms in a teacher's calculation: social status, salary, student achievement, and time. It is important to note that the costs and benefits are not necessarily actual but perceived. Thus when a teacher faces a new way of doing things, she makes a value judgment based on her current knowledge, beliefs, and attitudes, which are deeply grounded in her current practices and the school culture in which she teaches.   These decisions are critical to teacher successes and because teachers are keystone species, their decisions affect others' uses and opportunities for success.

The perception that a certain way to use the computer may lead to less student learning, requires excessive amount of time, make the teacher look bad before the students, or cause legal and ethical problems adds to the cost side of the equation. So does the perception that the use may demand dramatic changes in teaching practices, upset social relationships, or negatively affect the identity as a teacher. For example, many survey studies found that although many teachers use the Internet to look for information themselves and assign students to use the Internet as a research tool, very few make use of it as a tool for students to communicate with others(Becker, 1999; Zhao, et. al., 2001). This may have resulted from the perception that it is difficult to control what students do and with whom they communicate in live Internet communications, as well as other security and legal issues. It could also be that teachers do not feel communicating with others necessarily "teaches" anything.

In contrast, the perception that a certain use may improve student learning, public image of the school and teacher, reduce workload, or improve social status adds to the benefit side of the equation. So does the perception that a particular use leads to more resources, salary increases, or simply better relationships with colleagues. At least one of the reasons that teachers frequently use the Interent for lesson planning(Becker, 2001; Cattagni & Farris, 2001; Zhao, et. al., 2001) is that it they perceive it to be an easy way to locate instructional resources.

The perception of costs and benefits is determined and mediated by a number of factors, including pedagogical beliefs and styles, knowledge of and attitudes toward the computer, perception of support from schools and colleagues, perception of pressure to use computers, perception of adequacy of resources, and perceived results or consequences of use. However, there is no direct linear causal relationship between one factor and the perception of cost and benefit. For example, technology proficiency or knowledge of the computer may reduce perceived cost. However, it is also conceivable that those who know more about computers may think learning to use computers takes more time than those with less knowledge. It is also possible that technology proficiency does not affect the calculation at all in some cases where the teacher receives on-demand, prompt technical support from colleagues or school or the use of the technology requires very little technical knowledge.

Many of the factors identified by previous research affect computer uses through influencing the teacher's calculation of costs and benefits, which, in the ecosystem metaphor, is the driving survival force. Their effects can be categorized into five groups: increase cost, reduce cost, increase benefit, reduce benefit, and no effect. Table 1 presents an analysis of the effects of some of these factors within our framework.

Table 1 is intended as an illustration of how many of the factors previously identified can be accounted in our framework: they affect teacher's calculation of costs and benefits associated with computer use. It is not meant to be an exhaustive list of all factors. Moreover, given that the effect of some of these factors is often the result of interactions among several variables, the nature of effects presented in the table should be taken only as suggestive.

Insert Table 1 about here

Previous research often cast these factors as determinants or static factors that affect computer uses at a certain time. The ecosystem metaphor, in contrast, considers the interaction between two species as a dynamic process, wherein they co-evolve and adapt to each other. For example, teachers can change their attitude toward computers and reinterpret the functions of computers. 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 can help achieve their goals, hence reduce perceived costs and increase perceived benefits.

For members of a species that live in groups, within species interactions and reciprocal altruism are very important in terms of both exerting pressure and providing help to each other. Thus, given the social nature of teachers, we need to examine teachers' interactions with computers through a social capital lens (see Frank, Zhao, & Borman, submitted). First, teachers may exert pressure on each other to use or not use computers or use the computer in certain ways, depending on the norm of the social group. Teachers can also provide support and help to each other. The pressure to use computers can turn into perceived benefits because by using the computer, the teacher conforms to the pressure and retains her membership. Help from colleagues can help reduce "costs" associated with using computers.

To summarize, within this framework, while there are many different possible factors, which can reside at multiple levels of the educational hierarchy, what ultimately directly determines the amount and type of computer use by a teacher are two things: the nature of the use and the result of the teacher's cost-benefit analysis of the use. All other factors contribute to these two things. In other words, these factors do not directly influence technology uses in a linear fashion, but rather their influence is mediated by and filtered by teachers' perceptions.

Our framework places emphasis on the dynamic process between the teacher and the computer. It highlights "opportunities" or "practices" that may help change teachers' perceptions rather than merely seeking static correlations between isolated factors and computer uses. Figure 1 illustrates the framework developed from an ecosystem metaphor. First the ecosystem metaphor naturally represents the multiple levels of schooling (Barr & Dreeben, 1977, 1983; Bidwell and Kasarda, 1980; for a review, see Frank, 1998) in terms of the nesting of systems and subsystems. Of course, not all processes are neatly organized by the nesting structure. Just as weather events can penetrate all levels of an ecosystem simultaneously, so institutions (e.g., use of Windows, presence of computer labs, etc.) can penetrate multiple levels of schooling simultaneously. Similarly, resources can be allocated to schools from any level, delivered either directly to schools or through block grants allocated from one level to the next. Figure 1 also shows how the teacher serves as keystone species, governing the way new technology will ultimately interact with students, and existing teaching practices and technologies. Finally, driving the teacher's action is her beliefs and perceptions regarding the value of technology.

Insert Figure 1 about here

Study Design

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 were selected from one Midwestern state. Since our interest was also to assess technology uses and understand what might affect the level and type of technology uses in schools, we needed schools that had technology available to teachers and students. Thus we only selected schools that had made significant investments in technology between 1996 and 2001.

Operationally, the criteria used to select districts for participation in the study included recent passage (between 1996 and 2001) of a bond referendum or receipt of a community foundation grant for implementation of technology, the willingness of the Superintendent of Schools to participate in the study, and the size of 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 tend to be smaller and relatively tightly defined social systems. Schools being a level of our hierarchy, we were also interested in understanding possible building level differences, so we included all elementary schools in the selected districts. In order to obtain the complete picture of technology uses we administered the survey to all school staff. We offered incentives to schools for high response rates and to individual teachers to come as close as possible to enumerating the entire faculty population. Ultimately we achieved a response rate of 92% or greater in each of our nineteen schools.

Table 2 presents background information of the sample school districts. These data suggest that our sample had more access to technology than the national average (Cattagni & Farris, 2001). We also compared our samples with other schools in the same state on other background variables. Not surprisingly students attending the sampled schools came from slightly higher income families than the average in terms of percentage 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 expenditure, student teacher ratio, and school size.

Insert Table 2 about here

Data Collection

We collected three types of data: survey of all staff; interviews with administrators, technology staff; and interviews and observations in one focal school in each district. The survey included 33 various format items (e.g., Likert Scale, multiple choice, and fill in the blanks). The interviews were semi-structured 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 mainly focused on the technology infrastructure of a building. The data collection was completed in the spring of 2001. A professional independent research firm was contracted to perform the data collection.

Findings and Analyses: Interpreting Technology Uses from an Ecological Perspective

In this section, we report findings of the study within the theoretical framework developed earlier in this paper. This framework draws upon the ecosystem metaphor that considers the introduction of computers in schools as an organic process akin to the process by which an alien species is introduced to a new ecological context. This section includes three parts. Part 1 reports findings on current uses of technology. Part 2 describes measures of the various factors associated with uses of teacher and student computers in particular. Part 3 presents findings of a statistical model that delineates factors that influence computer uses.

Current Technology Uses in Schools

To what degree are technologies used in schools?

Table 3 presents the percentage of teacher reports of the frequency of their use of common school technologies for educational or professional purposes. The most frequently used technologies are phone systems, email, and computers in the classroom. This finding is consistent with an ecosystem metaphor in which simpler technologies requiring little adjustment to existing practices are more frequently used. Interestingly, teachers use computers more in the classroom than in the computer lab, which is somewhat contrary to the observation of Loveless (1997). This may be the result of recent investment in more and better computers in the classrooms. It is also the case that computers in the classrooms are more convenient to use for the teacher, especially when they are used for simpler functions such as surfing the Internet and processing emails.

Insert Table 3 about here

Note that though little previous research attends to the phone system, the phones are used almost daily. The phone, albeit not as complex a technology as the computers, can be a powerful communication tool for teachers. Frequent uses of the phone could transform the teacher from being isolated in the schoolhouse (Tyack & Cuban, 1995) or classroom (Lortie, 1975) to potentially integrated with parents, colleagues, other schools, and community members. Thus the phone is critical in integrating different layers of the ecosystem.

Drawing on the ecosystem metaphor, these different technologies can be considered potentially complementary or competitive. Clearly a phone 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 being integrated with computer technology. But perhaps not considered as frequently is the potential for technologies to be competitive. If teachers rely increasingly on phones 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 presentations on computers for the same. Clearly from the anatomical standpoint these are different technologies. But from the ecosystem standpoint they may compete for the same niche, that is, the same function in the teacher's professional life.

What Kind of Technology Uses are Teachers Engaged in?

Besides levels of uses of various technologies, we focused specifically on the types of computer uses in schools. Here we go beyond asking about percentage of time teachers or students used computers, to ask about *how* computers were used because computers, unlike phones, hold the potential for qualitatively different types of uses. This draws on the ecosystem metaphor, focusing on in what ways species interact rather than just the frequency of interaction. As previously discussed, we differentiate teacher uses of the computer from student uses, consistent with the motivations of the teacher as selfish organism and as member of a system, as are species in an ecosystem.

Table 4 presents the percentages of frequencies of teacher and student activities using computers. The overall reliability of the measure of student uses is .75 and 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 are communication with parents and preparation for instruction, while the least are activities directly involving students using the computers (e.g., student to student communication, remediation, student inquiry, and student expression). This finding again confirms the assumption that simpler technologies that require little change, thus 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. Communication with parents and preparation for instruction are much simpler to implement than uses that involve students because the latter requires teachers to re-configure their teaching practice while the former does not.

Table 4 also suggests that teachers use computers more for communication with parents than with students. In light of teachers' frequent use of the phone, we may hypothesize that teachers have a strong need to break down Lortie's walls—teachers have the need to communicate with parents and colleagues, but the necessary technology was absent at the time of Lortie's study. This is an empty niche for this type of computer uses. Teachers' infrequent use of computers for communication with students may be explained by the fact that presently most communication with students occurs face-to-face in the classroom.

It seems evident that like organisms in an ecosystem, teachers use computers to address their most direct needs, which brings them maximal benefits, in ways that do not demand excessive investment in time to learn and reorganize their current teaching practices, thus minimizing costs.

Insert Table 4 about here

Factors and Practices Affecting Technology Uses in Schools

In this part we describe our measures of factors that have been previously identified to have a possible impact on school technology uses. We then assess the importance of each factor in an overall model (see Table 5). Using the ecosystem metaphor, we organize our factors according to those defining the ecosystem, the teacher's niche, teacher-ecosystem interaction, teacher characteristics, teacher-computer interaction (as species to species), and opportunities for adaptation. Factors included in this study were selected from two bodies of literature: 1) research on technology uses in schools and 2) the literature on the diffusion of innovations. We indicate factors described in the diffusion literature (e.g., Tornatzky and Fleischer, 1990; Wolfe, 1994) with bold (# items indicate those found to be strongest general predictors of diffusion by Tornatzky & Klein, 1982). All measures are based on a 7-point Likert scaling ranging from "strongly disagree" to "strongly agree" unless otherwise specified.

We present the categories of factors as organized in Table 5 in reverse order.

Ecosystem

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

Niche

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. This can be considered a component of the ecosystem, but due to its potential explanation power, we list it as a separate category.

Teacher-system Interaction

Teacher perception of district support: the extent to which teachers perceive adequate support from the district. In the ecosystem metaphor, this affects the teacher's cost-benefit analysis. Two measures were used, one for hardware (alpha=.88) and the other for software (alpha=.88), based on composites of responses to items with the stem: "Please rate the district in terms of the following …":

Hardware:

providing enough hardware;

choosing appropriate hardware;

providing a reliable server;

updating hardware;

providing technical support for hardware use;

Software:

providing enough software;

choosing appropriate software;

updating software;

engaging teachers in decisions about software purchases;

providing professional development for software uses;

providing technical support for software use;

recognition for technological innovations.

Adequacy of Resources and Support: the extent to which teachers feel it is easy to implement technology in their teaching. In the ecosystem metaphor, this is a measure of the conditions facilitating co-evolution and it affects teacher's cost-benefit analysis when considering implementing computers. Based on a composite of the following items (alpha=.80):

The computer resources in my room are adequate for my instructional needs (e.g., lesson and unit planning, accessing materials such as pictures);

The computer resources in my room are adequate for student uses (e.g., student research, writing, artwork);

It is easy to implement new software in this school;

It is easy to implement new hardware in this school.

Help received from colleagues. Following Frank, Zhao, and Borman (submitted), we developed a measure based on the total amount of help each teacher received from others. Critically, social capital theory suggests it 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 conveyed by the help depends on the expertise of the provider of help. Expertise could not be independently measured by teachers' use of technology at a time prior to the provision of help, therefore it cannot 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 provide help to others, the more expert she was. Thus, the measure of social capital we used was based on the amount of help teachers received, weighted by the extent providers of help helped others. Ultimately we developed two measures of help, based on help received from close colleagues and help received from others who were not listed as close colleagues, differentiating 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 provider and receiver, as distinguished by whether provider and receiver were close colleagues or not. This differentiation may help sort out whom teachers perceive as their own species or group, as suggested by the theory of reciprocal altruism.

Pressure to use computers: Frank, Zhao, and Borman 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 clan conform to peer pressure. We measured social pressure through two items (correlated at .26):

> Using computers helps a teacher advance his/her position in this school;
>
> Others in this school expect me to use computers.

Presence of competing innovations: In the ecosystem metaphor, multiple invading species may compete for resources and thus systems may be limited in their capacity to accommodate multiple changes. Measured with one item:

> We introduce many new things in this school.

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

Teacher (native species) Characteristics

General tendency to innovate: In the ecosystem metaphor, this is characteristic of a species or individuals of a species indicating the likelihood of interacting with an invading species. Measured with the following three items (alpha of .74):

I try new things in the classroom;

I am one of the first to try something new in the classroom;

I enjoy introducing something new in the classroom.

Teacher-Computer (species-species) Predisposition to Compatibility

#compatibility: Potential users are more likely to implement technology that is consistent with existing values, past experiences, and needs of the potential implementer (Tornatzky & Klein, 1982). Compatibility is similar to “magnitude” (Beyer & Trice, 1978) and disruptiveness (Zaltman, Duncan, & Holbek, 1973) in that highly compatible innovations do not require large displacements of organizational states. In the ecosystem metaphor this reflects the inherent compatibility of the two species, teacher and computer uses. Two compatible species tend to have less negative interactions, at least commensal, if not mutualistic. Measured with the following four 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;

It is easy to integrate computers with my teaching style.

#complexity: Potential users are more less likely to implement technology they perceive to be complex (Tornatzky & Klein, 1982). This is similar to ease of use (Davis, 1989; Igbaria & Iivari, 1995; Mumford & Gustafson, 1988), self-efficacy and uncertainty (Zaltman et al, 1973). In the ecosystem metaphor, this reflects the energy required for adaptation between teacher and technology, thus costs associated with using technology. Measured with a single item based on the percentage of time a teacher was able to solve technical problems on her own.

***#relative advantage**:* Potential users are more likely to implement technology that gives them an advantage relative to the idea it supersedes (Rogers, 1995; Tornatzky & Klein, 1982; Zaltman et al, 1973). This is similar to centrality – the degree to which the 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, 1973) and perceived usefulness (Davis, 1989; Hage, 1999; Igbaria & Iivari, 1995). In the ecosystem metaphor, this is the advantage to teachers as rational actors in a competitive environment. Measured with two sets of items for perception computers can help teachers (alpha=.92) and perception that computers can help students (alpha=.89):

Computers can help me...

integrate different aspects of the curriculum;

teach innovatively;

direct student learning;

model an idea or activity;

connect the curriculum to real world tasks;

be more productive.

Computers can help students...

develop new ways of thinking;

think critically;

gather and organize information;

explore a topic;

be more creative;

be more productive

Teacher Professional Development (opportunities for adaptation)

Given our ecosystem metaphor, we view professional development as opportunities for species-species co-evolution and mutual adaptation. Interestingly, 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 therefore as mutually exclusive activities. Therefore we explored effects of the following activities separately:

Seek help from others to learn about new technologies

Read professional journals about new technologies

Explore new technologies on my own (*playfulness*: Agarwal & Prasad, 1997).

Attend district or school in-service programs for new technologies

Attend professional development conferences about new technologies

Consult technology manuals

An Ecosystemic Model of Influences on Technology Use

In the next section, we use multiple regression to evaluate relative relationships among the factors and teacher and student use of computers. We use the ecosystem metaphor to organize the presentation, reporting increases in $\underline{R}^2$ as a result of adding each set of factors, from eco subsystem designation through opportunities for adaptation. We present findings from interviews and observations along with the survey results. Note that because our schools were all commonly embedded in the same state (and therefore federal) government, as well as exposed to the same societal institutions, we did not account for these explicitly in our models, although they are represented in our theory. We restrict our discussion to factors with standardized coefficients of magnitude greater than .1 and of statistical significance $\underline{p} \leq .05$, although we take relationships with standardized coefficients between .07 and .1 and statistically significant at $\underline{p} \leq .10$ as suggestive.

Insert Table 5 about here

Our findings support a multilevel, richly contextualized set of influences that we interpret with respect to the ecosystem metaphor. To begin (at the bottom of the table), there were moderate differences among districts (districts accounted for about 11%-14% of the total variation for student and teacher use of computers respectively). Once districts were accounted for, differences among schools accounted for less than one tenth of a percent of the overall variation (this finding was confirmed with multilevel models). This was surprising to us, essentially suggesting that the district, not the school, defines the primary subsystem. This may be accounted for by the fact that when it comes to technology, policy, investment, expertise, and professional development are addressed at the district level, leading to essentially a uniform pattern of implementation across all schools in a district. It may well be that though the subsystems of schools are certainly distinct from each other because they contain different populations, the effects of subsystems defined by schools do not differ from each other. Similarity is only in the aggregate of use, not in the pattern of distribution or in the interaction around the use. Each community has its lion and its lamb, even if they are not the same lion and lamb.

Our observations and interviews suggest that the four districts indeed have different practices and policies with regard to technology hardware and software purchase and distribution as well as focus and content of professional development. For example, in terms of professional development approaches, one district took a more concerted approach than the others. In this district, professional development efforts are sequenced so that every teacher can start with basic skills and then move on to curriculum integration. This district also offers separate professional development programs for new teachers during the summer. The district technology director is adamant about having teachers within her district lead the professional development rather than bringing outside providers. District level leadership is very responsive to teachers needs and continuously assesses teachers' needs to find out what teachers need in professional development, software, and hardware. These practices are 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 organized.

Regardless of whether the school or district defines the ecosystem, most of the variation in computer use is within the ecosystem. To begin, the teacher's niche, defined by his or her structural location, part of the abiotic component, had large impacts on use. Teachers of English were especially likely to use computers and teachers in 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. In other words, 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.

Niches accounted for increases in $\underline{R}^2$ of 7% to 20%, thus supporting arguments that simple structural positions differentiate adoption rates. Combining the effects of districts with teachers' niche, we can see that the "abiotic component" of teachers' instructional ecosystem account for a large portion of the variation, which is consistent with the ecological metaphor that suggests compatibility between the life-history characteristics of the invading species and the conditions of the new environment plays a critical role in its success.

Moving up, teacher-ecosystem interaction accounted for an additional 11% to 14% of 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:

> 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!

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

This finding is consistent with Frank, Zhao, and Borman's (submitted), findings of how social capital affects usage. But here the rationality of social capital is presented within the context of the ecosystem 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. On the other hand, teachers' own actions may be more responsive to local social contexts, including social pressure of other teachers. Thus the ecosystem can be both a help and a hindrance. Others are more willing to help when the focus is on common students. On the other hand, the ecosystem can demand compliance, at least in terms of a teacher's individual behavior.

There is strong support for the ecosystem hypothesis that new species compete with each other. Teachers who perceived their school implements many new innovations were less likely to implement computers for student uses 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, and moderately so for their own purposes. Note though still based on self report, this predictor is related to teachers' behaviors, suggesting that both perceptions of the ecosystem and interactions with it are important.

Compatibility accounted for an additional 5% to 8% increase in R2. Most importantly, the more a teacher believed that computers were compatible with her teaching style the more 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 ecosystem metaphor under the concept of mutualistic interactions with the invading species. Finally, teachers who perceive a relative advantage for computers for themselves reported more usage for themselves and moderately for their students. Again, this confirms Tornatzky and Klein (1982), but casting it as relative advantage within the ecosystem metaphor helps us understand why the perceived advantage to the teacher (as opposed to the student) may be particularly important.

Finally, opportunities for adaptation added 1% to 3% to the variance explained in computer usage (controlling for all previously reported effects). Most importantly, teachers reported more usage of computers when they had explored new technologies on their own. This exploration likely enabled teachers to better understand the value of technology and develop the ability to use technology, thus reducing the perceived costs of using technology. It could also be that the teacher changes her pedagogical beliefs and practices and thus sees 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.

Summary[i]

The ecosystem metaphor provides a framework for many of the individual findings. Factors designating the ecosystem, niche, teacher-ecosystem interactions, teacher predispositions for compatibility and opportunities for mutual adaptation each had unique and important relationships with reported uses of computers. Moreover, the ecosystem metaphor offers a subtle distinction between sets of relationships. Specifically, teacher predisposition for compatibility was more important for teacher use of computers while teacher-ecosystem interactions were more important for student use of computers (with the exception of perceived pressure to use computers, which may operate as much on predispositions for compatibility as directly on computer use)[ii]. Thus teachers were more responsive to the subsystem in engaging in behaviors that position 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 relate to new technology in their ecosystem as individual organisms as well as members of a larger social system.

Discussion

The primary purpose of this article was to develop and test a framework from an ecological perspective to capture the organic process of technology uses in schools. The key findings of this study are depicted in Figure 2. Figure 2 consists of three progressive (evolutionary) pictures that illustrate the stages of technology adoption. Please note that this is not to suggest that there are only three stages in this process. We view this process as ongoing, thus each of these can be viewed as representing a moment in time, connected to the past and leading to the future. Starting with the top phase, the district On the left of the figure) provides the hardware, establishing the presence of the technology. This district force is shown transcending the barrier of the school, because any variation in technology associated with schools could be attributed to districts in our data. District in-service technology attempts to mediate between teacher and technology, but is shown as barely entering the school (top of the figure), based on our empirical findings. This is analogous to the arrival of the zebra mussels in the Great Lakes. Attached to boats and ships, zebra mussels were distributed across the Great Lakes as these vehicles were moved from one place to another. Their survival depended on where they settled.

At the same time that the technology is introduced into the school, other forces enter the school. 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. Similarly, there are many exotic species which enter an ecosystem such as the Great Lakes due to human activities and natural forces. Some of them may survive while most do not.

Insert Figure 2 about here

At the center of each phase is the interaction between a focal teacher and technology. Initially, the technology has a certain capabilities, represented by the shape of the technology. The teacher perceives the value of the technology that may reflect the teacher's history, pedagogical practices, etc and assess the costs associated with the use. In phase 2, the teacher and technology change shapes as they co-evolve. Note that the teacher's modifications are influenced by the help she receives and pressure she perceives from others (shown by the dotted lines). These other teachers may themselves be reacting to institutions or other forces exogenous to the school. This is analogous to the settlement process of an invading species, wherein it interacts with the native species that can be a food source, competitor, or predator. The compatibility between the invading species and native species influence their survival. This also shows how forces of the larger ecosystem are conveyed by relationships within the subsystem of the school.

In the last phase, the technology begins to conform to the teacher, as teachers develop the capacity to modify software and hardware to suite their needs. In the meantime, the teacher can also change how she interacts with the computer, which may suggest and demand different ways of teaching. This is the stage of co-evolution, where both 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 instructor, while the computer becomes a tool to support that. It could also be that the teacher finds the intended uses of the computer completely incompatible and stops using it. In a very unlikely scenario, the computer uses could become so pervasive that the teacher is transformed into a different role in the school and the teacher, in her traditional sense, becomes extinct.

The focal teacher also continues to change shape as she interacts with the teacher originally exposed to the new curriculum or other innovations (dashed line). This change can make the focal teacher less compatible with the new technology, thus showing how multiple innovations can compete with each other. This, in the ecosystem metaphor, happens when multiple exotic species invade an ecosystem, which forces the native species to adapt to all of them. As a set, the phases 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 ecosystem metaphor. In particular, the informal help and information teachers provide to each other have important associations with computer use that are comparable to those of more commonly accepted 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 cracks in the school day and outside of the school context are critical to technology implementation. This finding strongly supports the fundamental concept of the ecological metaphor in that mutual adaptation between species, especially between existing and new species, takes frequent contact and active interactions at a local level.

Ultimately, the informal social organization of the school filters many of the effects on technology use. Following the ecosystem metaphor, teachers' immediate local ecology plays a vital role in shaping their reactions to technology, an alien species introduced into the ecology. 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 is important for teachers is their peers in the local environment.

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

Implications for Research

The eco-system metaphor seems to be a powerful way to organize and examine the various factors associated with technology uses in schools. This metaphor suggests that future research should pay more attention to understanding the relationships and processes of how the various factors affect technology uses in schools rather than identifying new factors. Some possible lines of inquiry derived from this metaphor include the following.

First, this framework implies that the process of technology adoption is one of co-evolution. Thus a factor may play different roles at different times. For example, experimentation with technology may be more important after a teacher is already introduced to the basics of technology. Since participants in our study are from school districts that had already been promoting technology uses for some years, the dynamics of the ecosystem may be different from those schools that are either at the beginning or a later stage of technology adoption. Therefore, one of the suggestions for future research would be to study schools that are at different stages of technology adoption.

Second, this model draws special attention to teachers' rational calculation of costs and benefits of adopting technology, or any innovation for this matter. This calculation is based on perception rather than "reality." It would thus be fruitful to investigate what influences teachers' perceptions and how teachers' perceptions can be changed most efficiently.

Third, this study highlights the vital role of local context, i.e., the ecology where teachers work, in filtering external resources, opinions, and innovations. In the terms of our metaphor, it would be beneficial to further explore the internal social dynamics among existing species and new species. Of particular interest is to continue the exploration of what constitutes keystone species and how they affect others in the process of technology adoption.

Fourth, in this article, we propose to view uses of computers, instead of computers as a physical object, as the invading species. In other words, we are interested in not only how much computers are used but also how computers are used. This proposal was in response to three observations of computer uses in schools. The first is that computers as hardware are quite common in schools. So the concern is no longer over the dispersal of computers per se, but computer uses. The second observation is that computers can be used and are used in many different ways(e.g., drill-and-practice vs. project learning, student use vs. teacher use), with different implications for education. Thus the concern now is not whether computers are used but how they are used to facilitate the core tasks of teaching and learning. The third observation is that different uses seem to have different "survival rates" in different settings and across settings. In the ecosystem metaphor, the success or failure of the invading species depends much on the compatibility between its own characteristics and the conditions of the new environment. While in this study we compared student and teacher uses, we did not carefully examine the characteristics of the more desired uses of the computer and under what conditions they may survive. Hence future research can specifically investigate the interactions between different types of uses for students and their interactions with the teaching ecosystem.

Fifth, the ecosystem metaphor stresses dynamic interactions between species and species with the system. Such interactions drive co-evolution. In other words, while the invading species may need to change to adapt to the ecosystem it enters, it can also change the ecosystem and its native species. The zebra mussels in the Great Lakes are a good example. Thus as certain uses of computers are adopted by teachers, it will be important to study their effects on the school and teachers, to study what is replaced, what is changed, and what is maintained.

Finally, the ecological metaphor implies competition among species. In this study we examined the usage of multiple technologies (e.g., phone, email, etc.) and multiple uses of one technology (computers). We did not, however, look at the interactions between other species in the teaching ecology (e.g., books, references, libraries etc.) and technology. It would be fruitful to study these interactions as they may prove to be major sources of factors that influence the uses of technology. If we are to take the ecological metaphor seriously, we would assume that the resources in an ecology (in this case teachers' time and energy, student time and attention, and district resources) are fixed. Spending more time and energy on one species would mean a reduction of time and energy on other species. Consequently if a teacher uses books or worksheets more, she will by definition use the computer less.

Implications for Policy and Practice

In drawing policy implications we note two important caveats. First, our sample is moderately more advantaged than the average elementary school in the state in which the study was conducted. In this sense our schools are not representative, although they may provide a glimpse into the near future for other schools who will soon invest in technology. Furthermore, our sampled schools come from only four districts, and thus, we have a very little information about a key source of variation. Second, we analyzed cross-sectional data. Thus we know many factors that are correlated with computer use, but any causal inferences are weak, and therefore policy implications should be cautious. That said, we endeavor to draw some preliminary policy implications. Finally, we suspend our application of the ecological metaphor so as to be as direct as possible in our application to schools.

Districts can influence 10-15% of computer use through the decisions they make to hire technology directors, provide resources, and establish a general vision for technology use, and this has non-negligible effects on computer usage. Thus districts should undertake these decisions carefully.

But most of the variation in implementation of computers is within schools. Therefore we must focus on the teacher level factors that affect usage. The factors associated with computer usage map onto four basic mechanisms for change: recruitment/selection, training/socialization, providing opportunities to explore and learn, and leveraging through the social context. First, teacher characteristics such as grade and subject and the extent to which computers complement the teaching style are important predictors of computer usage. But the most likely mechanism for affecting changes in this category is through attrition and recruitment/selection. The clear policy implication is to consider how adaptable a teacher will be to computers technologies during the hiring process.

Second, change agents can provide training opportunities such as through in-service and professional development conferences. But our evidence suggests that these activities may have little effect on usage in the classroom for the common teacher. Most likely they operate through socializing teachers into different beliefs regarding the value of technology.

Third, change agents can provide various opportunities to explore and learn about new technologies. These have surprisingly strong effects on both teacher and student use of computers. This suggests that districts could do well simply to allow teachers release time to engage technology and consider its applications *within their specific* contexts.

Fourth, change agents can leverage 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 through the social context is a double-edged sword. As help is most important when coming from a colleague, those with few colleagues may not be able to access the type of help they need to implement computers. Also, social pressure can be as strong a force working against technology as in favor of technology. This suggests that change agents should be very 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 implement computers less when they are asked to implement many other new things. Change agents should thus be aware of the stress on the social context and culture before attempting to implement further innovations.

Our findings suggest several programmatic possibilities. First, instead of spending time on in-service programs and conferences, districts could spend their resources giving teachers opportunities to explore computer applications. Encouragingly, teachers are already engaging in these types of behaviors relatively frequently, but it is uncertain how much of this activity is supported by districts. Second, teachers should 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. But these interactions should be guided and focused on increasing levels of technology use. Third, schools that try to adopt multiple innovations simultaneously may find that none are fully implemented. Thus schools should limit the number of innovations they try to implement and devote ample resources on those they do choose.

These proposals can be summarized as:

1. Consider teaching style as it complements computer usage when hiring teachers.
2. Give teachers opportunities to experiment with software and demonstrated applications;

3. Consider providing opportunities for teachers to interact instead of standard professional development;
4. Focus on a small number of innovations at any given time.

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 sub-systems that are like small ecologies. Thus change agents must account for the extent to which organisms in the ecosystem are prepared to accommodate change (implication 1), they must allow opportunities for co-adaptation (implication 2), they must allow for adaptation through the social processes of the system (implication 3), and they must not overburden the system (implication 4).

Conclusions

In this paper, we proposed an analytical framework drawing upon the ecosystem metaphor. We then presented a study that applied this framework to understanding technology uses in schools. Finally, we discussed several implications for future research and policy and practices. We now conclude this paper with a few general cautions, suggestions, and hopes.

First, although the ecosystem 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. It should not be carried too far. Metaphors, when carried too far, can be dangerous and misleading. While we do not yet know exactly the boundaries of this metaphor, we hope that our readers will not attempt to impose all theories and practices about the biological ecology onto the human social system.

Second, that said, the ecological metaphor indeed helped us better understand computer uses in schools. What we learned from the zebra mussels proved to be useful for interpreting its less successful counterpart—the computer in schools. It took us beyond simply identifying and correlating factors. Instead it focused our attention on interactions, activities, processes, and practices. This metaphor may also prove to be useful for understanding other types of educational innovations.

Third, the ecological metaphor emphasizes the systemic implications of the introduction of any innovation. Accepting the ecological metaphor, innovations cannot be implemented oblivious to the internal social structures of schools or other pressures schools must face. By the same token, we view attempts at systemic reform as ambitious as attempts to reform whole ecologies, which is extremely difficult. Thus we suggest an evolutionary rather than revolutionary approach to school change.

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Appendix: Factors listed by Wolfe (1994) not explored

We did not explore the following characteristics (described by Wolfe, 1994) because we hypothesized they were of limited relevance in studying the impact of computer technology in schools:

divisibility: the degree to which the innovation is a ‘tight’ package of interlinked parts as opposed to being a ‘loose’ composite of independent parts that could be adopted separately (Tornatzky & Klein, 1982). The software uses of computers are, by definition, independent parts and constant across schools.

observability: the extent to which the results of an innovation are visible to others (Tornatzky & Klein, 1982). Preliminary analyses of pilot data indicated this was not a strong predictor of innovation adoption. Instead we explored the effect of perceived status and pressure to use computers.

physical properties: differentiates material or physical object innovations from social, programmatic, or process innovations (Warner, 1974). This is similar to form (Rogers, 1995) or material versus social innovations (Tornatzky & Fleischer, 1990). We did not include measures of physical properties because computers take multiple forms, and we anticipated this was less salient for computer innovations than for mechanical innovations in manufacturing.

skill: the extent of specialized expertise or training needed to use the innovation effectively (Meyer & Goes, 1988). This construct is similar to complexity, which we did measure. Furthermore, we assumed most people need some training in how to use computers for specific tasks.

Figure 1
New Technology in the Ecology of the Classroom

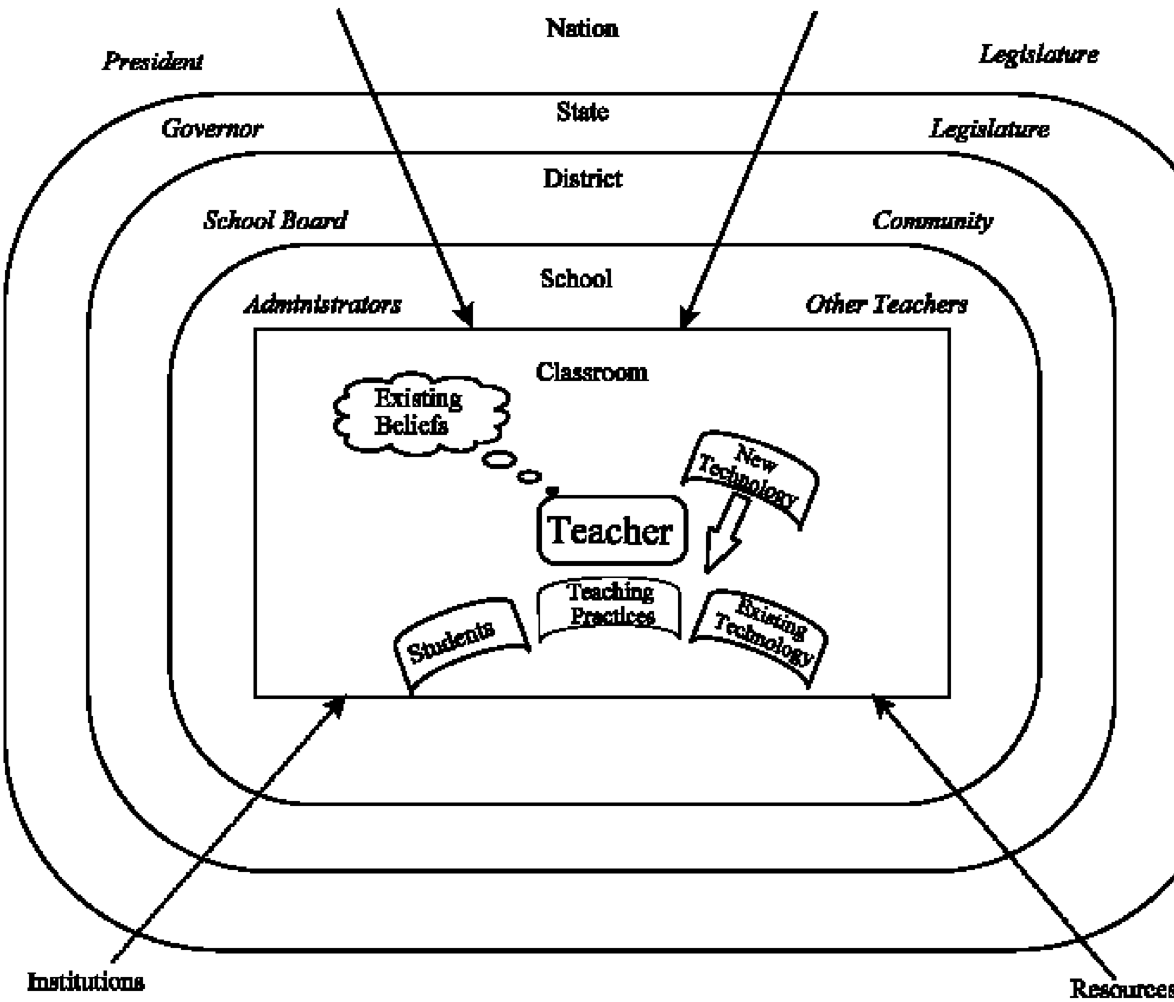

Figure 2
Coadaptation in the Classroom

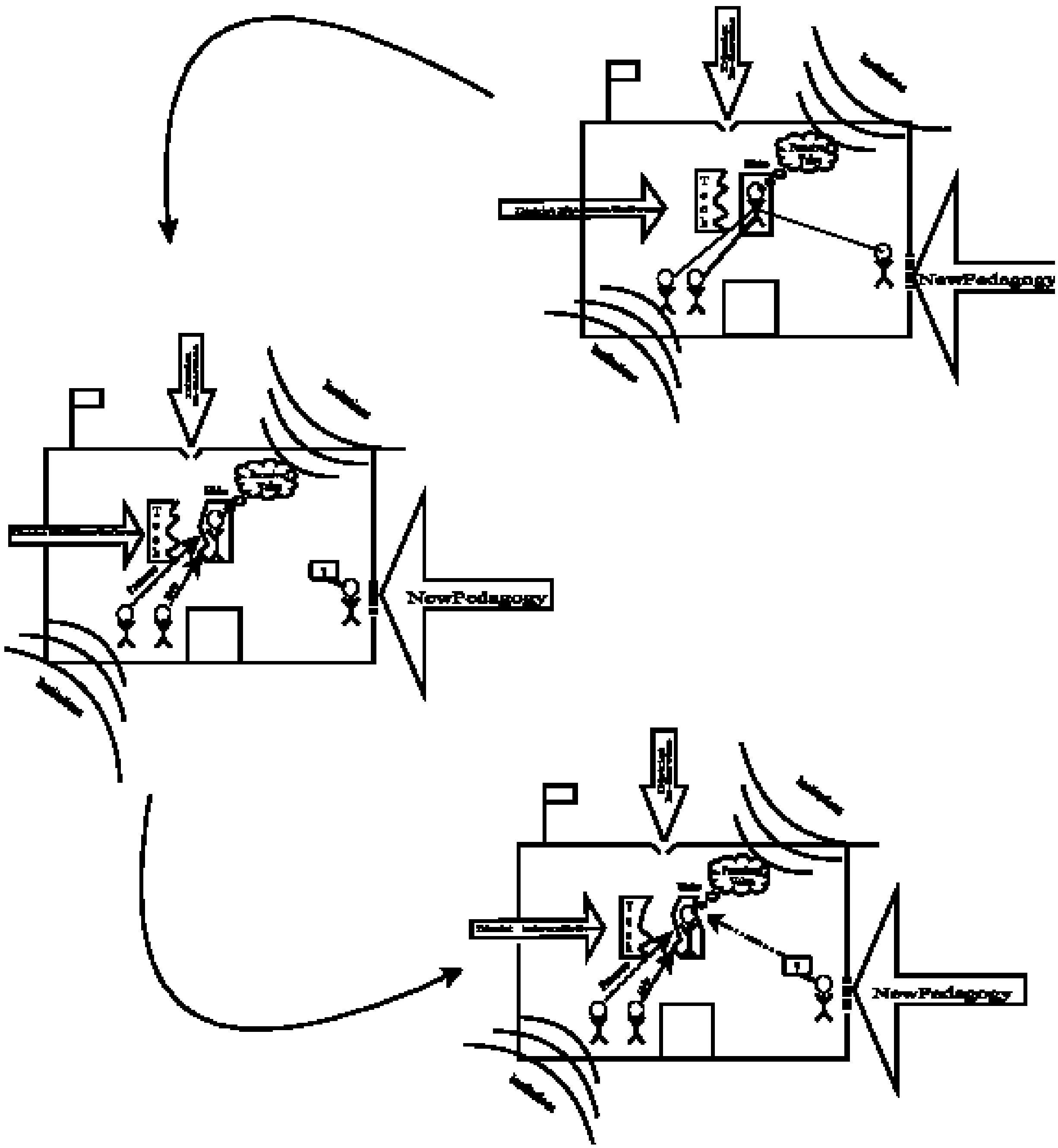

Table 1: Factors Affecting Teacher Perceptions of Cost and Benefits

Source	Factor	Benefit	Cost
	Inflexible scheduling	0	+
School	Lack of adequate technical support	0	+
	Lack of easy access to computers	0	+
	Inadequate technology infrastructure	0	+
	Active social network around computer uses	+	-
	High technology proficiency	0	-
Teacher	Positive attitude toward technology	+	0
	Progressive teaching approach	+	0
	Constantly changing technology	0	+
Computer	Conflicting views about technology uses	-	0
	Unreliable/unstable technology	-	+

Note: 0 = no effect; + = increase; - = reduce.

Table 2 Background Information of Districts

District	Student Population	District Type	Student/Computer Ratio*
A	2041	Rural/Suburban	5.1
B	5111	Suburban	4.9
C	1638	Rural-suburban	2.9
D	7158	Rural/Suburban	4.4

Note: Student computer ratio is average for all district instructional computers as of March 2001.

Table 3 Frequency of Technology Uses

	Never (%)	Yearly (%)	Monthly (%)	Weekly (%)	Daily (%)
Phone 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
World Wide Web(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 your school's lab (M= 3.45)	10.50	10.10	11.00	60.70	7.70
Computers in your classroom (M= 4.57)	5.10	0.70	4.10	11.70	78.30

Note: % = percent of teachers reporting frequency of use

Table 4. Frequencis 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., newsletters, e-mail, class Web page) (M= 3.38)	11.20	5.60	29.50	41.00	12.60
Teacher-student communications (e.g., response to written work, posting 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., reward 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., publish student work on a Web page, 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., repeat a lesson, Accelerated Math, Jostens) (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

Table 5. Factors Affecting Technology Uses in Schools[iii]

	Student Use of Computers		Teacher Use of Computers	
	Unstandardized Coefficients (Standard Error)	Standardized Coefficients	Unstandardized Coefficients (Standard Error)	Standardized Coefficients
(Constant)	.0369		.4793	
	(.280)		(.346)	
Opportunities for Adaptation		R^2=.52		R^2=.43
explore new technologies on own	.0524	.057	.1852***	.174
	(.043)		(.054)	
seek help from others	.0800[a]	.073	.0436	.034
	(.048)		(.060)	
read professional journals about new tech	.0837[a]	.076	-.0036	-.003
	(.045)		(.055)	
Teacher Predisposition for Compatibility		R^2=.51		R^2=.40
Perceived Compatibility	.1105*	.123	.1714**	.165
	(.047)		(.058)	
Perceived complexity	.0318	.039	.0578	.061
	(.032)		(.040)	
Relative advantage: computers can help the teacher	.1065[a]	.113	.2007**	.185
	(.054)		(.067)	
Relative advantage: computers can help the student	-.0426	-.038	-.1154	-.090
	(.059)		(.073)	
Teacher-system Interaction		R^2=.46		R^2=.32
Help from close colleagues	.0082**	.103	.0007	.007
	(.003)		(.004)	
Help from others who are not close colleagues	.0020	.049	-.0008	-.016
	(.002)		(.002)	
Pressure to use computers	.0284	.044	.0779*	.104
	(.027)		(.033)	
Presence of Competing Innovations	-.0922**	-.114	-.0729[a]	-.078
	(.033)		(.041)	
Playfulness (experiment with district supported software)	.1693***	.188	.0973[a]	.094
	(.044)		(.055)	
attend district or school in-service programs for new technology	.1185[a]	.072	.1229	.065
	(.068)		(.084)	
Niche		R^2=.32		R^2=.21
Teaches English	.4481***	.247	.2999**	.143
	(.090)		(.111)	
grade teacher teaches	.0727**	.189	.0395	.089
	(.023)		(.029)	
teaches multiple grades	-.0695	-.036	-.0163	-.007
	(.116)		(.143)	
missing grade information	.0620	.020	.3276[a]	.090
	(.160)		(.198)	
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	

[i] Other Factors

Factors described in the measures section but not reported in Table 4 were discarded because their coefficients suggested they were neither substantively important nor statistically significant. We left a few factors in the model to establish that they were not associated with use of computers, *once controlling for other characteristics*. These were the perceived complexity of computers, the perceived relative advantage of computers for students, and help from others who were not close colleagues. We needed to control for perceived complexity before interpreting the association between help received and use because there are some teachers who are high users but receive little help because they themselves perceived that computers were not complex or difficult to use. Indeed, the coefficients for help received increased once controlling 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 depend most directly on their own uses and needs (note that perceived relative advantage for students had larger coefficients before controlling for perceived relative advantage for teachers). Finally, it is important to establish that help from those other than close colleagues had essentially zero relationship with reported use whereas help from colleagues is highly related to student use of computers (the coefficients are different by more than two standard errors). Thus it appears that help is more important when the provider and receiver share an immediacy in the ecosystem.

[ii] Though the pairs of coefficients are in general not statistically different (see Cohen and Cohen, 1983, page 111, for the test between two coefficients.), as a set the trend supports an interesting and valuable interpretation.

[iii] Note that because the outcome variables for teacher and student use of computers were originally correlated at .55, we confirmed the results reported in Table 5 using a structural equation model (using the SAS Calis module accounting for the correlation between the two outcomes). Most estimates and standard errors were within .02 of those reported in Table 4. Most inferences were confirmed, with the following exceptions:

- the coefficient for *Relative advantage: computers can help the student* approached statistical significance in the structural equation model for *teacher use of computers*;
- the coefficient for teaching English was considerably weaker and of borderline significance in the structural equation model for *teacher use of computers;*
- the coefficient for *reading professional journals* was statistically significant in the structural equation model for *student use of computers* while it was borderline as reported in Table 5.

The error terms for the two models were correlated at .28, indicating that these are relatively distinct behaviors after accounting for the independent variables.