A UNIFIED APPROACH TO THE DIFFUSION OF INNOVATIONS IN EDUCATION: COMPUTER NETWORKS IN THE ARLINGTON SCHOOL DISTRICT

by

Elson Y. Liu

B.S. Mechanical Engineering
Stanford University, 1994

Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Technology And Policy

at the
Massachusetts Institute of Technology
June 1996

Signature of Author: Elson Y. Liu
Technology and Policy Program
May 15, 1996

Certified by: ____________________
Ceasar McDowell
Assistant Professor, Graduate School of Education
Thesis Supervisor

Certified by: Lee McKnight
Lee McKnight
Lecturer, Technology and Policy Program
Thesis Reader

Accepted by: ____________________
Richard de Neufville
Chairman, Technology and Policy Program

Accepted by: ____________________
Ain A. Sonin
Chairman, Committee on Graduate Studies

A Unified Approach to the Diffusion of Innovations in Education: Computer Networks in the Arlington School District

by

Elson Liu

Submitted to the Technology and Policy Program
on May 15, 1996 in Partial Fulfillment of the
Requirements for the Degree of Master of Science in
Technology and Policy

ABSTRACT

The implementation of technology in education is cyclic - increasing and decreasing with each attempted application of a new technology to classroom practice. A new technology for education is introduced, expectations are raised, research is conducted indicating educational effectiveness, little to no diffusion of the innovation takes place, and then expectations are left unmet. This thesis first identifies the factors influencing successful diffusion of innovations in education, and evaluates the technology strategy pursued by the Arlington, Massachusetts public school district with respect to those factors. The factors are developed from an examination of the historical cycle of educational technology, historical approaches to education reform, and diffusion of innovations theory. This thesis hypothesizes that a successful diffusion strategy for computer networks in education should address the situational constraints on teacher choice, the historical legacy of top-down education reform, and the attributes of the innovation that will influence adoption. Arlington's unified approach - creating a coalition of stakeholders to use and fund the network and combining network deployment with planned school building renovation - is seen to address many of these factors.

Thesis Supervisor: Ceasar McDowell
Title: Assistant Professor, Harvard University Graduate School of Education

Thesis Reader: Lee McKnight
Title: Lecturer, MIT Technology and Policy Program

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my family, whose support has made this endeavor possible, both educationally and financially. I am forever in their debt.

I would also like to thank my advisors Ceasar McDowell and Lee McKnight, whose patient guidance and long efforts have been significantly responsible for making the completion of this thesis possible. My thanks also to my fellow students in the MIT Technology and Policy Program for their suggestions, support, and camaraderie.

I am also grateful to the many individuals and organizations whose time and knowledge have contributed to this work:

At MIT, the co-authors of the report on the technology and policy options for Arlington: Nils Fonstad, David Gingold, Paul Greenberg, Takashi Hoshino, Yongwon Kwon, Brett Leida, Douglas Melcher, Joseph Reagle, jae Hun Roh, Grady Seale, Karl Sun, Hiro Tsuchiya, and Darren Zinner; also at MIT, Joseph Bailey, Sharon Gillett, Suzanne Neil, Russell Rothstein, and Richard Tabors.

In Arlington, the many contacts and interviewees over the past two years: Don Bochler, James Brown, Doug Clare, Brian Clough, Teresa DeBenidictus, Richard DeCaprio, Antonette DiLoreto, Kathleen Donovan, John Dunlap, Jane Foley, Charles Foskett, Shelley Glantz, Ellie Jackson, Mary Kierstead, Doreen Killdan, Bob Lynch, Ted Mael, Michael McCabe, Phil McCarthy, Alan McClennen, Helen McGah, Joe Miksis, A.L. Minervini, Jane O'Grady, Mary Ellen Powers, Caroline Simmons, Herb Yood, and the students of Arlington High School.

In Massachusetts, other contacts and contributors: Tom Hsu, Joanne Krepelka, Mike Leone, Connie Lui, K. Scott Nickerson, Kathleen Raphaelson, Joe Schabetti, Walter Stroup, and Mark Wheeler.

Finally, I would like to thank my Christian family at MIT, especially the Graduate Christian Fellowship and the Chinese Bible Fellowship, and in particular my friends Andrew Douglas Crabtree and Erin Tracy O'Neill, all of whom have been the hand of God in my life here. Psalm 104: 31, 33.

TABLE OF CONTENTS

Chapter 6: Factors Affecting Education Network Diffusion in Arlington, MA

Chapter 7: Beyond Arlington

LIST OF TABLES AND FIGURES

1 INTRODUCTION

1.1 Overview

> Our...challenge is to provide Americans with the educational opportunities we'll all need for this new century. In our schools, every classroom in America must be connected to the information superhighway, with computers and good software, and well-trained teachers. - President Clinton, in his 1996 State of the Union Message[1]

> I don't see this as new, grandiose spending by any means. This is an important priority for education, and it's worth trying to figure out where the money can come from. - Under Secretary of Education Marshall Smith, in response[2]

The policy could not be more clear - providing every classroom in the United States with a modern telecommunications infrastructure. Likewise, the problem could not be more clear - funding that infrastructure investment. While modern telecommunication networks are prevalent in business and quickly becoming available in homes, such networks for primary and secondary education are rare and developing slowly. Indeed, technology in education has often been promoted as a means to improve education; thus far, however, the results of past educational technologies have been disappointing. Presidential policy statements notwithstanding, the question remains whether computer networks in education will face the same fate.

1.2 Problem

This thesis examines the diffusion process of a particular technology in a particular educational context - computer networks in the Arlington, Massachusetts Public School District. While innovation in computer networks have become prevalent in business and government, computer networks for education remain rare; thus far, this trend appears to follow the historical pattern of other educational technologies. In Arlington, however, extensive plans for deploying computer networks in the schools are being developed, and may provide insight into the potential for diffusion of computer networks in education.

---

[1]Clinton, W. recorded by “Prepared Text for the President’s State of the Union Message,” The New York Times. Jan 24, 1996, p. 14.
[2]Smith, M. quoted by Applebome, P. “Computer Idea Gets Mixed Response,” The New York Times. Jan 25, 1996, p. 17.

We hypothesize that Arlington's unified approach - creating a coalition of stakeholders to use and fund the network and combining network deployment with planned school building renovation - will be seen to address many of the factors influencing the successful diffusion of innovations in education.

1.3 Argument framework

The framework of the argument in this thesis follows three tracks to identify the factors influencing successful diffusion of innovations in education: the historical cycle of educational technology, historical approaches to education reform, and diffusion of innovations theory. The strategies used in Arlington are then examined to determine to what extent Arlington's situation is consistent with theory, and the implications for future policy in Arlington. This thesis argues that Arlington's unified approach to the diffusion of computer networks - unifying the technology deployment process with a capital infrastructure renovation plan and creating a unified vision drawing upon broad community support - should be successful in diffusing computer networks throughout the district.

1.4 Assumptions

The unit of analysis in this study is the Arlington public school district. Arlington was selected because it is in the midst of developing a technology strategy for deploying computer networks throughout its schools, providing a unique glimpse into a detailed decision-making process.

The factors influencing successful implementation are culled from an examination of the experience with past educational technologies, historical approaches to education reform, diffusion of innovations theory, and suggestions from the current experiences of other communities. Those factors are generally considered in terms of their positive or negative impact, although the magnitude of every factor's impact has not been determined. However, since cost has consistently been cited as a significant factor, two quantitative cost models are used to examine cost in more detail.

The cost models used in this study examine the cost of capital - the cost of putting machines and wires into place. The first cost model examines the incremental cost of deploying computer networks within a school building, between schools, and ultimately connecting to the Internet. The second cost model examines a staggered deployment strategy for investment. Neither model calculates the monetary cost of support and training, nor do they calculate infrastructure retrofitting costs which may be required for new furniture, power systems, ventilation, and space.

Arlington's technology strategy is analyzed by examining historical records and interviewing key decision-makers. Since self-reported evaluations are subjective, a distinction is made between planned actions, reported strategies, and idealized goals.

2 HISTORY OF EDUCATIONAL TECHNOLOGY

2.1 Overview

> For a technological revolution is sweeping through the U.S. and world economies that is totally transforming the social role of learning and teaching. This learning revolution already has made the 'classroom teacher' as obsolete as the blacksmith shop...We have the technology today to enable virtually anyone who is not severely handicapped to learn anything, at a 'grade A' level, anywhere, anytime. - Lewis J. Perelman, 1992[3]

> I believe that the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks...The education of the future, as I see it, will be conducted through the medium of the motion picture...where it should be possible to obtain one hundred percent efficiency. - Thomas Edison, 1922[4]

Has anything changed in 70 years of technology in education? Judging from the claims historically made by advocates of educational technology, perhaps not. Both Edison and Perelman, like many other researchers, educators, and politicians, look to educational technology as a means to radically change education. Indeed, they point to the revolutionary nature of technology, supplanting obsolete methods of education, and promising an educational nirvana where students perfectly achieve perfection.

Nevertheless, studies comparing new educational technologies with traditional methods of teaching consistently find that the new technologies are as effective as traditional methods, and at a lower cost. "More, Better, Faster, Cheaper" is the characteristic objective sought by advocates of educational technology,[5] and evidence of success can be found for technologies ranging from the film projector to the computer.[6]

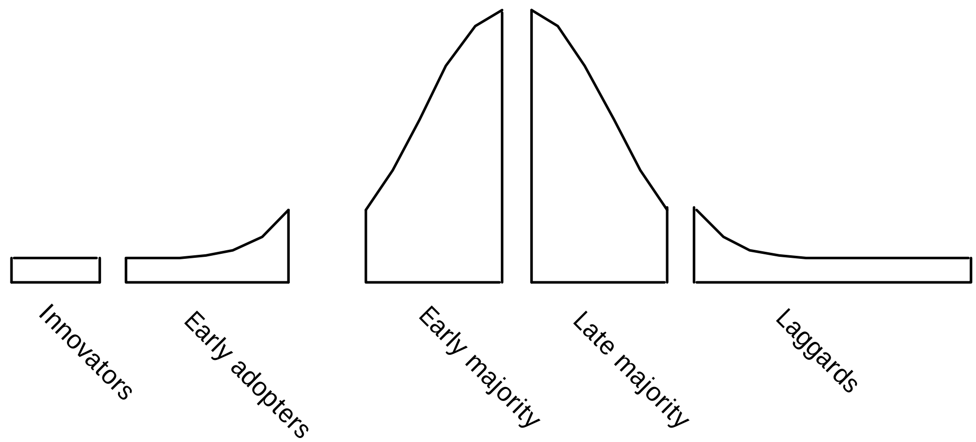
After the technology has seemed to prove itself in research, these advocates then wait with bated breath for the innovation to diffuse throughout the educational establishment,

---

[3]Perelman, L. School's Out: A Radical New Formula for the Revitalization of America's Educational System. New York: Avon Books, 1992. pp. 20, 23.
[4]Edison, T. quoted by Cuban, L. in Teachers and Machines: The Classroom Use of Technology Since 1920. New York: Teachers College Press, 1986. p. 9.
[5]Perelman, p. 182.
[6]Cuban, p. 5.

progressing along the diffusion curve to saturation just as a new television or VCR technology would in the consumer electronics market. The educational technologies do diffuse beyond the innovators stage, up to the early adopters stage, but time and again fail to cross the critical threshold to the so-called early majority stage.[7]

Figure 2.1 Adoption Rate Model



Source: U.S. Congress, Office of Technology Assessment, Teachers and Technology: Making the Connection, OTA-EHR-616. Washington, DC: U.S. Government Printing Office, April 1995, p. 133.

This simple model could be used to describe not only educational "innovations" such as film, radio, television, or computers, but also other school reform "innovations." The twentieth century history of education reform has also been marked by periodic calls for non-technology reforms such as "accountability, or community control, and 'compensatory education.'"[8]

Thus, the limited diffusion of technology in education is similar to that experienced with other modern education reform efforts. The lack of successful reform, in turn, often results in criticism against intransigent teachers or an inflexible bureaucracy. This "exhilaration / scientific-credibility / disappointment / teacher-bashing cycle" is a theme of modern education reform, and particularly of the attempt to integrate technologies into the classroom.[9]

---

[7]See chapter 4 for other contributions from diffusion of innovations research.
[8]Tyack, D. The One Best System: A History of American Urban Education. Cambridge, MA: Harvard University Press, 1974. p. 8.
[9]Cuban, pp. 5-6.

2.2 Historical Examples

The historical cycle of educational technology can be traced through the use of film, radio, television, and computers. Following is a brief summary of those attempts to implement educational technologies:

Films for educational use appeared at the beginning of the twentieth century, as early as 1910 in the Rochester, New York school system.[10] However, by 1954, only 23% of teachers in urban school districts used films "frequently" at the secondary level, as reported by administrators in charge of audio-visual departments.[11] Time-and-motion studies of teacher use of instructional film further estimated an average use of approximately one film per month per teacher.[12] Thus, decades after its introduction, and before reformers looked to instructional television as the technology of the day, use of film in classrooms remained limited and infrequent. One reason given for infrequent use was the "[t]eachers' lack of skills in using equipment and film."[13]

Radio for educational use began when the U.S. Department of Commerce licensed educational stations in 1920. In the early 1940's, estimates of use of instructional radio ran upwards of 8 million of students per week, based on the number of sets available in classrooms. However, after surveys of teachers found that "regular" use by one or more teachers occurred in less than 20% of schools, those estimates dropped to less than 1 million.[14] One national survey found that 73% of schools district superintendents reported either "few" or "none" of the schools in their districts used radio for education.[15] Again, surveys investigating reasons for infrequent use found that one of the reasons was "[t]eachers not interested."[16]

Instructional television replaced film and radio as the technology of hope for education reformers in the 1950's. Unlike film and radio, however, the diffusion of instructional television was dramatically aided by investment from the Ford Foundation, the National

---

[10]Saettler, P. A History of Instructional Technology, cited by Cuban, p. 12.
[11]National Education Association, "Audio-Visual Education in Urban School Districts, 1953-1954," cited by Cuban, p. 16.
[12]Dale, E. "Impact of New Media in the Secondary School Curriculum," cited by Cuban, p. 16.
[13]Cuban, p. 18.
[14]Woelfel, N. and Tyler, K. Radio and the School, cited by Cuban, p. 23.
[15]Atkinson, C. Education by Radio in American Schools, cited by Cuban, p. 23.
[16]Woelfel and Tyler, cited by Cuban, p. 25.

Defense Authorization Act, and the U.S. Office of Education. Less than 2 decades after the FCC first allocated 253 channels for educational television, more than $100 million had been invested in instructional television.[17] Nevertheless, teacher use of television remained low even into the 1980's.

> Students spent more time going and coming from the bathroom than watching televised lessons. Recess, collecting lunch money, and pledges to the flag took far more of the instructional day than watching televised lessons.[18]

2.3 Computers and Networks

Although the technologies of film, radio, and television have not fulfilled the dreams of advocates of educational technology, the integration of computers and networks into education may hold more promise. Schools in the first few years of this decade have spent approximately $500 million on computer expenditures, more than on any other educational technology expenditures up until then.[19] Furthermore, a national survey of teachers found that nearly 70% of teachers reported that personal computers were "readily available," and over 40% of teachers reported using personal computers "regularly for instruction."[20]

An international study has further indicated that the United States leads the world in sheer numbers of computers in schools, with an estimated 5.8 million units in 1995, or roughly one computer for every nine students.[21] Indeed, nearly one hundred percent of American schools have some form of access to computers. However, nearly fifty percent of the computers in schools are outdated models, primarily 8-bit Apple II computers.[22]

Access to computers, as in access to film, radio, and television is only part of the diffusion picture. While computers seem to have penetrated schools to a larger extent than film, radio, or television, surveys investigating student use suggest that computers

---

[17]"Educational Broadcasting Facility Program: Grants for Education and Radio," American Education and American Council on Education, "Special Report on Federal Programs," cited by Cuban, p. 28.
[18]Faunce, R., Willis, J., Johnson, K. and Keller, P., cited by Cuban, p. 39.
[19]U.S. Congress, OTA, p. 92.
[20]National Education Association, Status of the American Public School Teacher, 1990-1991, cited by U.S. Congress, OTA, p. 92.
[21]Anderson, R. "Hardware Projections in K-12 Schools," cited by U.S. Congress, OTA, p. 94.
[22]Anderson, ed. Computers in American Schools: An Overview, cited by U.S. Congress, OTA, pp. 94-95.

are nearly as unused as those earlier technologies.[23] Estimates of student use range from less than half an hour per week per student to approximately three hours per week per student. In addition, estimates of the number of teachers using computers in their classroom vary depending on grade level and definition of a "computer-using teacher." At the extreme, if one defines a "computer-using teacher" as one which uses a computer with all of his students (rather than isolated students), then reported use is only 20% for 11th grade English teachers.[24]

Although it remains unclear how many school districts across the nation use wide-area computer networks, a broad survey in 1993 showed that 32 states and the District of Columbia had operational state-wide "instructional telecomputing networks." Six states had partially operational networks, and nine other states were in the planning process for such networks.[25]

Thus, as with earlier educational technologies, networked computers appear to have reached the "exhilaration" stage of the educational technology cycle. From prior experiences with other educational technologies, it is suggested that a significant factor influencing the diffusion of innovations into the classroom is the teacher.

2.4 Factors Influencing the Classroom Diffusion of Innovations

As mentioned above, a commonly cited constraint on the diffusion of educational technologies is the inability to adapt, resistance, or outright hostility of teachers towards a new technology. This constraint also appears more generally as "the explanation that social scientists have most frequently used to account for the success or failure of planned organizational change, namely, the ability of management or a change agent to overcome members' *initial* resistance to change" (italics in original).[26]

---

[23]The surveys do not appear to make a distinction between many students with little use and few students with much use.
[24]Becker, H. "Analysis and Trends of School Use of New Information Technologies," cited by U.S. Congress, OTA, pp. 102-103.
[25]Educorp Consultants Corp., Networks Now: The 1993 Survey of How States Use Telecommunication Networks in Education, cited by U.S. Congress, OTA, p. 115.
[26]Gross, N., Giacquinta, J., and Bernstein, M. Implementing Organizational Innovations: A Sociological Analysis of Planned Educational Change. New York: Basic Books, Inc., 1971, p. 8.

A more sophisticated view of teachers' resistance to change considers the constraints upon their ability to choose. Indeed, the market model of consumer adoption of technology makes an assumption that does not hold in education. "[A consumer is] free to decide himself whether the innovation shall be tried...This assumption does not apply to major educational innovations in most school situations."[27]

Rather than acting as consumers with complete freedom of choice, teachers are bound by constraints upon their actions. While not completely constrained to obey orders as in the military, teachers are still near the bottom of a vertical organization, facing instructions from a contingent of bureaucrats including expert policy-makers and professional administrators. Another significant constraint on teacher behavior is time - spent in preparation, in class, and in evaluation. Other constraints include the expectations to follow curricular guidelines, to establish classroom authority, to maintain student discipline, and to respond to established measurement instruments of their students' and their own competence. In this environment, the teacher's ability to act has been described by Larry Cuban as "situationally constrained choice"; that is, a form of choice not as free as a consumer purchase.[28]

From the perspective of situationally constrained choice, Cuban concludes that the impact on the classroom role of the teacher is a primary factor influencing the successful diffusion of an innovation.[29] Other factors addressing the acceptance of technology by teachers include the time and resources provided for professional development, and the provision of incentives for innovative behavior.[30] Thus, the factors influencing the classroom diffusion of innovations include:

• Incentives for innovative behavior

• Time and resources provided for professional development

• Impact of innovation on classroom role of teacher

---

[27]Gross, et. al., p. 21.
[28]Cuban, L. The Managerial Imperative and the Practice of Leadership in Schools. Albany, NY: State University of New York Press, 1988.
[29]Cuban, Teachers and Machines, p. 71.
[30]Perelman, pp. 225-226.

3 HISTORICAL APPROACHES TO EDUCATION REFORM

3.1 Quest for Efficiency

The recent history of education reform has been characterized by top-down efforts. The pattern of taking reforms from the corporate world and applying them to the educational domain can be traced to the early part of this century. At that time, the business philosophy of “scientific management” was sweeping through American industry. The ability of this industrial method to reduce costs *and* raise output set the criterion by which future innovations in organizational management would be measured: efficiency.[31]

The essence of scientific management, also known as the Taylor system for its inventor Frederick Taylor, was to replace the unscientific “rules of thumb” used by workers on the factory floor with the “one best method” of work, determined through scientific study. The studies, the administration of the method, and fundamental control of the work process would be placed in the hands of management; workers in turn would simply follow the prescribed “best method” of work, maximizing their efficiency.[32]

It was not long before the fascination with efficiency reached education, with both teacher and administrator associations sponsoring conferences and publications on the use of scientific management in education. As the Taylor system became better known, it also became more widely applied. The institution of education, large in size and supported by tax dollars, became an obvious target of criticism with respect to efficiency.[33] It was in response to this criticism that teachers and administrators began examining the application of the Taylor system to their work.

What was obvious, however, was the difficulty of quantitatively measuring “efficiency” in education. Like the infamous drunk man searching for his keys beneath a street lamp because the light was better there, the drive to apply the principles of scientific management to education resulted in a corresponding drive to develop standardized measures of educational efficiency.[34] Per-pupil spending ratios, grade point averages,

[31]Callahan, R. Education and the Cult of Efficiency. Chicago: University of Chicago Press, 1962, pp. 19-20.
[32]Callahan, p. 25-27.
[33]Callahan, p. 47.
[34]Callahan, pp. 97-98.

standardized test scores, and drop-out rates became the criteria by which the efficiency of education was measured, and the standards by which education reform were judged.

Thus, the philosophy of scientific management applied to education had several implications for education reform:

- It established the pattern of applying business practices to education, especially in methods of management.

- It resulted in the development of a "factory" model for education, where the goal was minimizing inputs while maximizing outputs.

- It suggested that there was a "one best method" of educating students, and argued for its discovery and subsequent universal application.

- It set the precedent of defensive reform in education, where reforms were implemented in response to criticism rather than adopted positively.

- It created a linked impetus for standardized, quantitative measures of performance for students, teachers, and administration.

Ultimately, it created a centralized, top-down paradigm for implementing change within the schools.[35]

3.2 Approaches to Reform

The themes from the history of education reform are also apparent in the history of the adoption of technology in education. The pattern of applying business practices was easily extended to the introduction of technology. For example, the success of computer-assisted learning systems in the vocational context is often cited as an indication of how useful such systems would be in an educational context. As one commentator quipped, "Mr. Goodwrench actually has more to tell us about the future of education than Mr. Chips ever imagined."[36]

---

[35]Tyack, pp. 126-147.
[36]Perelman, p. 27.

The factory model of education and its efficiency criterion also applies, with advocates of educational technology calling for “More, Better, Faster, Cheaper” education.[37] The phenomenon of searching for “one best method” also appears as a theme in educational technology, as the failure of old technologies (film, radio, television) are set aside in exchange for the promise of success in new technologies. And those technologies, like education reform efforts in general, are often adopted as a defense against criticism rather than from positive motivation.[38] Furthermore, the success of an educational technology is often measured by how much more information is learned by students, or how much better students perform on standardized tests.[39] Finally, another similarity with non-technological education reforms is the implementation of technology in education from the top-down, seeking “the apparent efficiency in introducing technology by fiat.”[40]

If one considers an organizational structure as a form of technology in a broad sense, it is not surprising to note that the top-down structure of school governance has resulted in unintended consequences. Rather than eliminating the influence of politics from the administration of the schools, centralized control has led to complex political interactions. Yet, the ideal of problem-solving through structural change persists, resulting in “a problem perennial in educational reform, namely the lure of the structural panacea and the bane of unintended consequences in behavior.”[41]

One of the unintended consequences of the vertical structure for school organization was the creation of two distinct views of that same structure. The view from the top might seem like a military command structure, with orders flowing from school board to superintendent to principal to teacher and ultimately to students.[42] Reforms were designed and implemented from this view, as if the mind of policy makers could be directly translated into the hand of teachers upon the lives of students. Yet the effectiveness of education reform remains limited by the fact that there is another view of the same structure - the view from the bottom. Reforms flowing from above in the “chain of command” do not necessarily elicit full compliance from below.

[37]Perelman, p. 182.
[38]Cuban, pp. 55-56.
[39]Cuban, pp. 34-35.
[40]Cuban, pp. 54-55.
[41]Tyack, pp. 168-169.
[42]Cuban, p. 56.

3.3 Education Reform: The Case of Desegregation

Perhaps the best-known structural reform of education in this century was the federal mandate to desegregate schools in the landmark 1954 Supreme Court ruling in *Brown v. Board of Education*. Seeking to address the racial inequities of a separate educational system for African-Americans, the Court reversed over half a century of the "separate but equal" legal doctrine expressed in *Plessy v. Ferguson*. No longer would separate facilities by race be permitted in education - integrated schools became a national right.[43] Perhaps indicative of the nation's faith in the power of technology, the solution chosen was a technological one - busing.

Comparison of the history of segregation in schools and the history of education reform reveals a bitter irony, for even as education reformers sought the "unifying force of the common school," they also allowed "separate schools for 'defective, delinquent, or...negro' children."[44] Indeed, segregation "denied the professed ideology of the common school, which in theory sought to mix all kinds of children under the unifying roof of the public school."[45] The implementation of desegregation, however, demonstrated how difficult top-down reform could be in the face of opposition. Changing policy, even changing the law of the land, did not translate into change at the classroom level.[46]

Indeed, the top-down theme of education reform, as in segregation, often focused on factors that could be measured and manipulated administratively:

> Redistributive policies, exemplified by Title I and school desegregation, were initially oblivious to questions of practice, instead emphasizing targeting resources and changing racial balance. As these policies matured, it became increasingly clear that their success hung more on school organization and classroom practice than on moving money and children...[T]he use of policy as an implement of reform grows out of a fundamental distrust of [teachers'] judgment. But the dilemma that

[43]Tyack, pp. 279-283.
[44]Tyack, p. 124.
[45]Tyack, p. 279.
[46]Tyack, p. 281.

> accompanies this use of policy is that the fate of reforms ultimately depends on those who are the object of distrust.[47]

The history of the integration of schools is complex and involves issues which are not necessarily pertinent to the discussion of educational technology. However, the battle over desegregation illuminates very clearly the weakness of top-down reform in education. Schools, even if mimicking the tight organizational form of corporations or the military, do not institute reforms in isolation from political influence. Rather than being immune to vagaries of political influence, *Brown* clearly demonstrated that schools could actually become a primary arena of political action.

3.4 Education Reform: The Case of Computer Technology

While no machine in the classroom is likely to arouse as much controversy as desegregation, integrating technology into education still faces political and institutional constraints. While the history of film, radio, and television in education was discussed earlier, the potential for computers in the classroom still remains debatable. Indeed, nearly every school district in the nation has some access to computers for some purpose, but this level of penetration does not necessarily mean that computers have successfully diffused throughout education. In describing the diffusion of computers in schools, Cuban describes it thus:

> For the principal, compliance with a school board's or superintendent's interest produces a few machines located in the library or the rooms of some teacher advocates. A few machines buy necessary insurance for withstanding criticism from parents and superiors for blocking the future. Such token adoption of an innovation, echoing earlier school responses to machines, not only insulates a principal (or superintendent) from static over the presence of modern technology in schools but also buffers unwilling or unconvinced teachers from the intrusive enthusiasm of boosters.[48]

Even a relatively non-controversial education reform, investment in educational technology, faces institutional constraints. Rather than acting as a "chain of command" where policies are fully translated into action, the vertical structure of school governance

---

[47]National Institute of Education, Rand Corporation, Elmore, R. and McLaughlin, M. Steady Work: Policy, Practice, and the Reform of American Education. Santa Monica, CA: Rand Corporation, February 1988, p. 34.
[48]Cuban, p. 77.

creates multiple "gatekeepers." Innovations can be stopped, or defensively adopted, at each level of decision-making. A school board might invest some money in a few computers as a response to local or state pressure; a superintendent might allocate some money towards a computer class or two in response to school board pressure; a principal might place a computer in the library as protection from the superintendent; a teacher might let one or two students use a computer for a project to forestall criticism from the principal.

3.5 Factors Influencing Technology Diffusion in Schools

Clearly, the top-down history of education reform in the United States has had limited results. Thus, factors influencing the successful implementation of technology in schools must address the legacy of past policies of education reform:

- Development of a unique concept for the educational use of the innovation, relative to industrial use

- Presence of non-economic motivations for deployment

- Multiple forms of use, to increase the potential for adoption

- Scope of support for the innovation, both within the schools and in the community at large.

4 DIFFUSION OF INNOVATIONS THEORY

4.1 General Definition and Process

There are several distinct definitions of “innovations,” with some focusing on the aspect of novelty, others on the aspect of process, and still others on the actual material object. The key aspect of innovations, however, is that they are “perceived to be new by the relevant unit of adoption.”[49] The emphasis on the perception of the adopter is especially appropriate for educational innovations, where technologies exist for many years in industrial practice before being applied to the classroom. However, focusing on the perception of the adopter can be problematic, since perceptions vary with changing contexts, shifting emotions, and even the passage of time. The perception of “newness” naturally erodes over time as the adopter becomes more familiar with the innovation.[50]

The diffusion of innovations has been variously described as a communication process,[51] the spread of ownership,[52] and even as a network phenomenon itself.[53] For educational innovations, the concept of diffusion has been described by two distinct ideas of physical access and classroom use.[54] In our case, the diffusion of computer networks in the Arlington school system refers to the deployment of a physical infrastructure (access), but for an explicitly educational purpose (use).

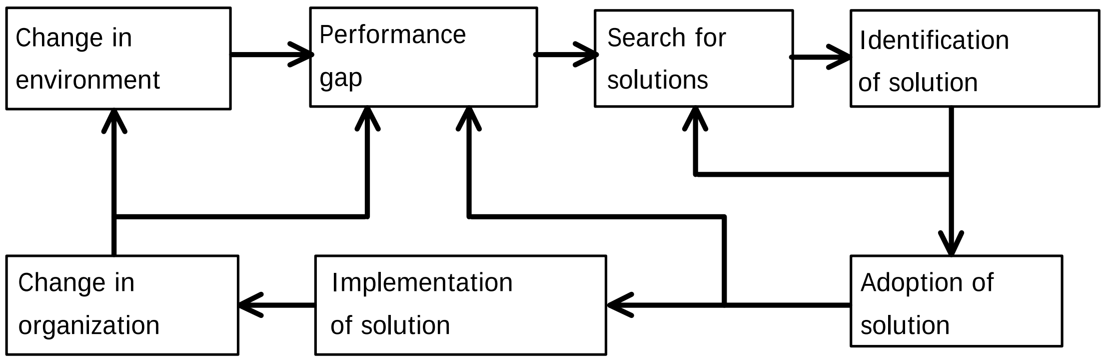
The perceived need for innovations and their diffusion can be described as a “performance gap,” a “discrepancy between what the organization could do...and what it actually does...”[55] In general, performance gaps are said to arise when there is a change in the external environment, requiring a corresponding change in the organization. In education, performance gaps can be a general sense of dissatisfaction with the performance of schools, or they can be highlighted by dramatic events such as the Soviet Union’s launch of the first man-made satellite.

---

[49] Zaltman, G., Duncan, R., and Holbeck, J. Innovations and Organizations. Malabar, FL: Robert E. Krieger Publishing Company, 1984, p. 10.
[50] Zaltman et. al., p. 13.
[51] Rogers, E. Diffusion of Innovations. New York: The Free Press, 1983, p. 5.
[52] Karshenas, M. and Stoneman, P. “Technological Diffusion,” Handbook of the Economics of Innovation and Technological Change, P. Stoneman, ed. Cambridge, MA: Blackwell, 1995, p. 265.
[53] Valente, T. Network Models of the Diffusion of Innovations. Cresskill: NJ, 1995, p. 2.
[54] Cuban, pp. 5-6.
[55] Zaltman et. al., p. 2.

From performance gap to implementation, the educational technology model of "exhilaration / scientific-credibility / disappointment / teacher-bashing cycle" can be seen as a specific case, and a more narrowly defined portion, of a more general diffusion model:

<u>Figure 4.1 Diffusion Process Model</u>



Source: Zaltman et. al., p. 5.

Traditionally, the implementation of technology in schools begins with the identification of a solution (radio, film, television, video, computer, and now networks), and ends just short of significant change in the organization. In the educational technology cycle described above, exhilaration arises at the identification of a solution, scientific-credibility persuades policy-makers to adopt the solution, disappointment comes when the innovation remains unimplemented, and teacher-bashing occurs when the performance gap remains.

Unfortunately, in the activity surrounding educational technologies, less attention is directed towards the initial stages of the diffusion process - recognizing the changes in the environment, defining the performance gap, and conducting a wide-ranging search for solutions. The remaining truncated approach may in itself have negative implications for the ultimate success of the diffusion process as a whole.

4.2 Factors Influencing Diffusion

In addition, several influential attributes of innovations have been identified in diffusion of innovations research. While several attributes can be categorized in terms of their expected positive or negative impact on the rate of diffusion, some factors influencing the diffusion process may be either positive or negative, depending upon the situation. Some attributes overlapping those developed from the historical surveys above, or overlapping with other attributes within the model itself have been omitted. For example, although “risk and uncertainty” is listed as a specifically negative factor, many other factors implicitly contain notions of risk and uncertainty in predicting their positive or negative impact on diffusion success (see **commitment**).

Positive attributes generally include financial returns to investment / efficiency, communicability, compatibility, perceived relative advantage, reversibility, and divisibility. Negative attributes generally include cost, complexity, required commitment, and the presence of gatekeepers. Factors which may have either a positive or negative influence include point of origin and terminality.[56]

Positive Factors:

- **Financial returns to investment / efficiency** is a common economic criterion used to evaluate technological investment. The time horizon and desired rate of return vary from organization to organization.

- **Communicability** refers to the facility with which the benefits of an innovation can be disseminated to other adopters. Linked to the concept of communicability is the clarity of results, the extent to which effects or changes can be attributed to the innovation.

- **Compatibility** refers to the extent to which an innovation is consistent with an organization’s goals and values.

- The **perceived relative advantage** of an innovation is determined with respect to its alternatives, including current practice.

- **Reversibility** is an attribute of the chosen implementation process which describes the ability of an organization to revert back to previous practice after adopting the innovation.
- Finally, **divisibility** describes the extent to which an innovation can be introduced in stages.

[56] Zaltman et. al., p. 47.

Negative Factors:

- **Financial cost** is a common economic criterion used to evaluate technological investment. Both initial costs and ongoing costs are considerations, as well as the extent to which an innovation will redistribute incentives within an organization.

- **Complexity** refers to the difficulty faced by potential adopters in understanding the innovation itself, its actual use, and its possible effects.

- **Commitment**, related to reversibility and divisibility, refers to the amount of resources, financial or otherwise, required to adopt the innovation. A large required commitment is considered to have a negative impact on adoption, because a larger commitment involves a sense of greater risk and uncertainty.

- Finally, the presence of **gatekeepers** refers to the presence of points in an organizational hierarchy where an innovation may be blocked, preventing adoption of the innovation at another level.[57]

Positive or negative Factors:

- The **point of origin** describes where the innovation came from **-** whether internal or external to the adopting organization.

- **Terminality** refers to the amount of time available for decision-making before the adoption of the innovation becomes impossible or undesirable.[58]

4.3 Impact of Factors: Stages of Diffusion Process

The broad survey above of the factors that influence the diffusion of innovations generalizes from several possible processes. Indeed, research models of such diffusion processes have been developed, emphasizing different factors and postulating different mechanisms by which certain factors influence the diffusion process.

[57]Zaltman et. al., pp. 35-44.
[58]Zaltman et. al., pp. 40-44.

For example, the diffusion process for adopting an innovation can be divided into several stages such as *knowledge*, *attitude formation*, *decision*, *implementation*, and *sustained implementation*.[59] The *knowledge* stage spans the period during which the potential adopter becomes aware of the innovation. The *attitude formation* stage is the period during which the potential adopter develops an attitude, either favorable or unfavorable, towards the innovation. Then, in the *decision* stage, the adopter chooses to accept or reject the innovation; that is followed by the *implementation* stage, where the innovation is actually put in use. Over a longer period of time, the *sustained implementation* stage is the period when the adopter either continues or discontinues use of the innovation.[60]

The factors influencing successful diffusion of an innovation (described in 4.2 above) come into play at different process stages. Using the 5 stage model described above, the factors may be grouped as follows:

Table 4.1 Grouping Factors with Diffusion Stages

	Diffusion Stages				
Factors	**Knowledge**	**Attitude Formation**	**Decision**	**Implement.**	**Sustained Implement.**
Efficiency		X			
Communicability	X				
Compatibility		X			
Advantage			X		
Reversibility		X			
Divisibility		X			
Cost		X	X		
Complexity		X			
Commitment			X		
Gatekeepers	X				
Origin	X				
Terminality				X	

Source: Zaltman et. al., p. 164.

[59]Zaltman et. al., pp. 163-164.
[60]Zaltman et. al., pp. 58-70.

Thus, it is postulated that the most important factors for the *knowledge* stage are communicability, gatekeepers, and the point of origin. Communicability of an innovation's benefits describes the ease with which information about the innovation is communicated to potential adopters; thus, it influences a potential adopter's initial awareness of the innovation. Gatekeepers regulate the transfer of information through an organizational hierarchy, which also influences a potential adopter's initial awareness. The point of origin also influences how quickly a potential adopter becomes aware of an innovation. The closer the point of origin is to the potential adopter, the more quickly the adopter becomes aware of the innovation.

In the *attitude formation* stage, the most important factors are postulated to be efficiency, compatibility, reversibility, divisibility, cost, and complexity. Efficiency and cost are the criteria used in an initial benefit / cost evaluation. Compatibility influences an organization's attitude towards an innovation to the extent that the innovation is consistent with the organization's values. Reversibility and divisibility refer to the level of commitment required to implement the innovation, and also affect the attitude of potential adopters. Finally, complexity is a factor that influences a potential adopter's understanding of an innovation.

In the *decision* stage, the most important factors are postulated to be perceived relative advantage, cost, and commitment. An organization will decide to adopt an innovation if the innovation is perceived to have a relative advantage over the possible alternatives. Also, cost and required commitment of resources may influence whether an organization is willing to adopt an innovation.

In the *implementation* stage, the most important factor is postulated to be terminality. The perceived immediacy of a terminal deadline can drive an organization to the *implementation* stage.

None of the factors identified from diffusion of innovations theory (section 4.2 above) are postulated to be the most important in the *sustained implementation* stage. However, some of the factors identified from the historical cycle of educational technology (section 2.4 above), historical approaches to education reform (section 3.5 above), or the cost analysis for Arlington (section 5.4 below) will play a role in the *sustained implementation* of an innovation.[61]

The 5 stage model developed by Zaltman et. al. is one example of a diffusion process model - other models may have more or fewer stages. Cuban, for example, implicitly uses a two-stage model in his research on educational technology, contrasting adoption of physical equipment with actual teacher use.[62] Unfortunately, it is difficult to generalize from one model to the next. The division of stages and categorization of factors depend upon the "particular problem and proposed solution(s), the nature of the organization, and the general context in which change is to occur."[63]

Fortunately, all is not lost. While different process models and different groupings of factors may not agree on the particular *mechanism* by which a factor influences the diffusion process, there is greater agreement on the expected *impact* of a factor on the diffusion process. For example, whether a high initial cost inhibits the diffusion process at the *attitude formation* stage or at the *decision* stage may be unclear, but what seems clear is that a high initial cost inhibits the diffusion process.[64] Further research is required to verify the mechanisms by which these factors influence the diffusion process at each stage.

While arguments may vary from model to model, the conclusions of the various process models are similar. Certain factors such as financial returns to investment / efficiency, communicability, compatibility, perceived relative advantage, reversibility, and divisibility are expected to have a positive influence on the diffusion process; other factors such as cost, complexity, required commitment, and gatekeepers are expected to have a negative influence on the diffusion process. Still other factors such as point of origin and terminality are expected to have either a positive or negative influence, depending on the situation.

---

[61] See section 6.5.1 and Table 6.1 for a full identification of the critical factors at each stage.
[62] Cuban, Teachers and Machines, p. 6.
[63] Zaltman et. al., p. 165.
[64] This example does not always hold true, as demonstrated by Fleigl et. al. in a study of the diffusion of farm practices. In that study, (cited by Zaltman et. al., p. 34) a high initial cost was actually found to have a positive impact on adoption, possibly because of a perceived cost-quality relationship. For computer networks in school systems, however, where funds are significantly constrained, cost is likely to be a negative factor.

A broad evaluation of these factors for a particular innovation in a particular organization, then, can address *whether* diffusion will be successful, if not precisely *how*. This thesis examines such factors - drawing not only from diffusion of innovations theory but also from the historical cycle of educational technology and historical approaches to education reform - for the case of computer networks in the Arlington school system. In addition, because cost is considered by policy-makers to be a significant factor in the diffusion of educational technologies,[65] a more detailed examination of the costs of networks follows.

[65] See section 1.1.

5 COST MODELING[66]

5.1 Cost Comparison

What are the technology options available to the Arlington school system for computer networks? To answer that question, several issues must be clarified.

First, although a computer network is not simply a set of wires that one purchases from a catalog of various manufacturers, it does have a physical definition in terms of the physical medium used by computers to communicate with each other. The common forms of that medium include twisted pair (a pair of copper wires twisted around each other as used in telephone wiring), coaxial cable (as used in cable television), optical fiber (thin strands of glass transmitting light), and electromagnetic waves (as in radio, microwave, infrared, or satellite communications).[67] The physical form of a computer network is defined by its physical attributes - where computers are located physically, what kind of communications medium is used, what kind of physical architecture is used, and so forth.

A computer network, however, has a more abstract, logical definition. The logical form of a computer network is defined by its abstract attributes, not its physical ones. For example, although two computers might be next to each other physically, they might be numbered on a network several stations apart. Also, a distance that is considered long physically may be considered short logically - a high capacity optical fiber over a mile can be a logically shorter link than a low capacity twisted pair line over a few hundred feet.

There are several more levels of abstraction of a computer network, each level defined by characteristics appropriate to that level.[68] The key technology choices faced by Arlington, however, fall close to the physical layer. *How many computers? What kind of wires? Where will equipment be placed?*

---

[66]This section is based upon a previous report co-authored by this author: Massachusetts Institute of Technology, TPP91: Proseminar on Telecommunications Modeling and Policy Analysis. "Computer and Network Technology in the Arlington Public School System." Cambridge, MA: MIT TPP, June 17, 1995, pp. 17-24.
[67]Bertsekas and Gallager, p. 56.
[68]See appendix for the reference model of computer networks defined by the International Standards Organization.

A previous study co-authored by this author examined the technology options available for computer networks in the Arlington school system.[69] There were three units of analysis in that study: a school building network, a district-wide network, and a network link to the global Internet.

Two cost models were then developed. The first model examined the incremental cost of computers, local school networks, the wide-area district network, and Internet access. This model provided a general sense of the cost of different levels of networks relative to the cost of the computers themselves, and established a baseline for comparison with other capital investments.

The second cost model examined the overall cost of computers and networks for three different levels of investment. These three deployment scenarios provided a general sense of the trade-off between financial costs and performance benefits. Scenarios using more advanced technology permitted more types of usage, but at a higher cost.

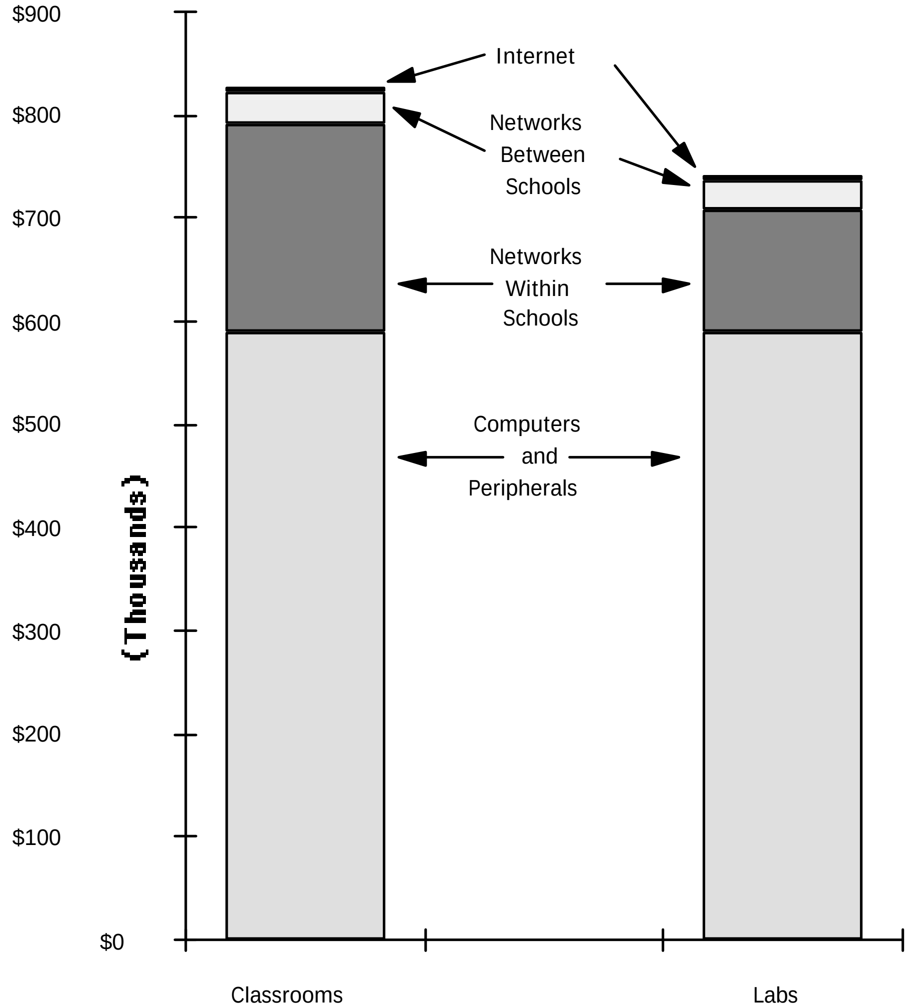
Together, the two cost models provide a comparison of the costs of different technology choices for computer networks in Arlington. They address the questions of *how much money do networked computers cost, compared to computers alone?* and *how much money does it take to get certain network capabilities, such as Internet access in every classroom?* Although these are not the only factors involved in the diffusion picture, the money / technology issue is a key factor in the feasibility of computer networks in Arlington.

5.2 Cost Model 1: Incremental Costs of Networks

The chart below summarizes the results from the first cost model, depicting the incremental costs of computers alone, networks within schools, networks between schools, and Internet connections.

[69]MIT TPP91.

Figure 5.1 Incremental Network Costs



Source: MIT TPP91, p. 17.

An examination of the results reveals several insights:

• Computers represent the primary expense: Even if full Internet connectivity is considered, the cost of computers alone represent roughly 70% of the total cost.

• The additional costs of networks are comparatively small: Networks inside the schools represent roughly 30% of the total cost, and networks between the schools represent only 5% of the total cost. Internet costs are very small compared to the rest of the computer and network costs.

• The cost of networks for labs is less than that of networks for classrooms: Because labs require fewer physical connections within the schools, lab network costs are somewhat less than classroom network costs.

The initial capital costs are not the only economic costs to consider, however. Ongoing costs (maintenance and replacement of equipment) must also be considered.

The following chart summarizes the initial equipment and annual ongoing costs for computers alone, networks inside schools, networks between schools, and Internet connections. The ongoing costs are displayed below the initial equipment costs.[70]

The annual ongoing costs for computers assume a 10% maintenance cost as well as a replacement cost every 7 years. The annual ongoing costs for networks within and between schools reflect only a 10% maintenance cost. The Internet ongoing cost is a typical annual fee charged by a service provider. None of the ongoing costs include the cost of support and training, which may be significant.

Table 5.1 Initial and Ongoing Costs

	Computers	**Networks Within Schools**	**Networks Between Schools**	**Internet**
Classrooms	Initial: $591,000 Annual: $144,000	Initial: $201,000 Annual: $20,000	Initial: $30,000 Annual: $3,000	Initial: $5,000 Annual: $6,000
Labs	Initial: $591,000 Annual: $144,000	Initial: $117,000 Annual: $12,000	Initial: $30,000 Annual: $3,000	Initial: $5,000 Annual: $6,000

Source: MIT TPP91, p. 18.

As in the capital cost comparison, the ongoing cost comparison shows that the incremental costs of computer networks are relatively small. However, the ongoing costs of computers themselves are significant, and should be carefully considered.

5.3 Cost Model 2: Deployment Scenarios

While the previous section focused on the cost of networks compared to computers alone, this section investigates three implementation scenarios for computers and networks in

[70]See Appendix for cost model details.

Arlington. For each scenario, deployment is staggered over a three to five year time horizon. A yearly budget is estimated.[71] The plans vary in terms of their technology choices and the corresponding monetary costs.

Several critical assumptions were made to make the analysis manageable. Based on data received from the Superintendent of Schools, it is assumed there are 96 usable computers within the Arlington school system. Each scenario results in a different total number of computers in use. Scenario 1 reaches 77 computers, yielding approximately a ratio of 50 students per computer; scenario 2 reaches 168 computers, yielding approximately a ratio of 25 students per computer; scenario 3 reaches 243 computers, yielding approximately a ratio of 17 students per computer.[72] The useful life of a computer, costing $2000 when new, is assumed to be seven years, after which the system is considered obsolete and replaced. Maintenance costs are assumed to be 10% of capital expenditures per year. Additionally, each option uses a single 56 kbps dedicated Internet access connection for the entire school system. Support costs are not included.

Finally, these scenarios are not meant to become a specific technology plan for Arlington, but rather to highlight the relative financial costs of different technology choices. The details of each example are presented to provide a sense of the technology choices available to Arlington.

5.3.1 Deployment Scenario A

Based on a three stage deployment plan, this example would have the following layout:

High School:
- Two computer labs (15 computers per lab).
- One high school file server.
- All computers connected to school network.
- 56 kbps Internet connection.

Junior High School:

---

[71] Future dollar values are not discounted in these budget estimates.
[72] Note that these student to computer ratios, although lower than the raw student to computer ratio nationwide, are calculated for modern computers replaced every 7 years. If the national student to computer ratio is calculated excluding older computers such as Apple II's, then the ratio is approximately 18.

• One computer lab (15 computers per lab).
• Computer lab with no network.

Elementary Schools:
• Computers in all 5th and 6th grade classrooms.
• No computers connected to the Internet.

Staged implementation:
Stage 1:
• Build network for computers in one high school lab (assume 15 existing computers available to network).
• Purchase high school file server.
• Purchase Internet service for latter half of stage.

Stage 2:
• Purchase computers for the second high school lab.
• Build network for computers in second high school lab and connect to school network.
• Purchase Internet service.

Stage 3:
• Purchase 15 computers for one junior high school lab (assume no existing computers available for junior high school lab).
• Purchase Internet service.

Ongoing costs:
• Purchase 11 computers to replace old equipment.
• Purchase Internet service.

Table 5.2 Scenario A

Stage	Computer cost	Networks within schools	Networks between schools	Internet	Total
1	$0	$10,400	$0	$4,500	$15,000
2	$35,200	$6,540	$0	$6,000	$48,000
3	$38,720	$1,590	$0	$6,000	$46,000
Ongoing annual	$34,628	$1,590	$0	$6,000	$40,000

Source: MIT TPP91, p. 20.

* The total number of computers would reach 77. There would be 34 in the high school, 15 in the junior high school, and 28 in 5th and 6th grade classrooms.

This low-level scenario provides a school-wide network within two high school labs. It also maintains a deployment of computers in the 5th and 6th grades, while providing the junior high school with one room of fifteen modern computers. In this scenario, the current support staff within the High School would maintain the system. The overall cost is low and the system can be upgraded in the future.

In such a deployment scheme, however, the junior high and elementary schools have no computer networks at all. In these schools, each computer must be loaded with individual software and no file sharing can occur. Connections between computers and printers become scarce and often create queues. Without a network between schools, eight of Arlington's nine schools do not have access to the Internet. Finally, a student / computer ratio of 50:1 is much higher than state and national averages.[73]

5.3.2 Deployment Scenario B

Based on a four stage deployment plan, this example would have the following layout:

High School:
• Three computer labs (15 computers per lab).
• One high school file server.
• All computers connected to school network and to district network.
• 56 kbps Internet connection.

Junior High School:
• Two computer labs (15 computers per lab).
• One junior high school file server.
• All computers connected to school network and to district network.
• Internet connection via district network.

Elementary Schools:
• One computer lab per school (5 computers per lab)

[73]See section 2.3 for a discussion of average student / computer ratios.

- Each lab connected to rest of district.
- Internet connection via district network.
- Stand-alone computers in all 5th and 6th grade classrooms.

Staged implementation:
Stage 1:
- Purchase 30 computers for three High School labs (assume 15 existing computers available for lab).
- Purchase high school file server.
- Build network for computers in all 3 labs and connect to school network.
- Purchase Internet service for latter half of stage.

Stage 2:
- Install district network on cable system between high school and junior high school.
- Purchase 30 computers for two junior high school labs (assume no existing computers available for junior high school labs).
- Purchase junior high school file server.
- Build network for both labs and connect to school network and to district network.
- Purchase Internet service.

Stage 3:
- Extend district network to four elementary schools.
- Purchase 20 computers for four elementary school labs (assume no existing computers available for labs).
- Build network for computers in all labs and connect to district network.
- Purchase Internet service.

Stage 4:
- Extend district network to remaining three elementary schools.
- Purchase 15 computers for three elementary school labs (assume no existing computers available for labs).
- Build network for computers in all labs and connect to district network.
- Purchase Internet service.

Ongoing costs:
- Purchase 24 computers to replace old equipment.

• Purchase Internet service.

<u>Table 5.3 Scenario B</u>

Stage	Computer cost	Networks within schools	Networks between schools	Internet	Total
1	$70,400	$20,300	$0	$4,500	$95,200
2	$77,440	$15,930	$15,000	$6,000	$114,370
3	$60,251	$11,220	$11,900	$6,000	$89,400
4	$53,323	$9,500	$10,340	$6,000	$79,000
Ongoing annual	$76,880	$4,730	$3,320	$6,000	$91,000

Source: MIT TPP91, p. 22.

* The total number of computers would reach 168. There would be 75 in the high school, 30 in the junior high school, 35 in elementary school labs, and 28 in 5th and 6th grade classrooms.

This mid-level scenario provides a better overall student to computer ratio (25:1). In this design, all schools have district- and Internet-connected labs. The High School would still maintain two labs without networks solely for the use of word-processing and other software applications. Stand alone computers (with no network connections) would still exist in the 5th and 6th grades, or allocated at the discretion of the district.

As can be seen from the chart, a mid-level scenario would have significantly higher maintenance costs. In addition, more support staff may be needed, significantly increasing the annual budget.

5.3.3 Deployment Scenario C

Based on a five stage deployment plan, this example would have the following layout:

High School:
• Five computer labs (15 computers per lab).
• One high school file server.
• All computers connected to school network and to district network.
• 56 kbps Internet connection.

Junior High School:
• Two computer labs (15 computers per lab).
• One junior high school file server.
• All computers connected to school network and to district network.
• Internet connection via district network.

Elementary Schools:
• One computer per K-6 classroom.
• One file server per school.
• All computers connected to school network and to district network.
• Internet connection via district network.

Staged implementation:
Stage 1:
• Purchase 30 computers for three high school labs (assume 15 existing computers available for lab).
• Purchase high school file server.
• Build network for computers in all three labs and connect to school network.
• Purchase Internet service for latter half of stage.

Stage 2:
• Install district network on cable system between high school and junior high school.
• Purchase 30 computers for two junior high school labs (assume no existing computers available for junior high school labs).
• Purchase junior high school file server.
• Build network for computers in both labs and connect to school network and to district network.
• Purchase Internet service.

Stage 3:
• Extend district network to three elementary schools.
• Purchase enough computers for each classroom in three elementary schools (assume 30 existing computers among the three schools).
• Purchase file servers for three elementary schools.
• Connect classrooms to school network and to district network.
• Purchase Internet service.

Stage 4:
• Extend district network to three elementary schools.
• Purchase enough computers for each classroom in three elementary schools (assume 24 existing computers among the schools).
• Purchase file servers for three elementary schools.
• Connect classrooms to school network and to district network.
• Purchase Internet service.

Stage 5:
• Purchase 30 computers for final two high school labs.
• Build network for computers in both labs and connect to school network and to district network.
• Extend district network to remaining elementary school.
• Purchase enough computers for each classroom in final elementary school (assume 8 existing computers in school).
• Purchase file server for final elementary school.
• Connect classrooms to school network and to district network.
• Purchase Internet service.

Ongoing costs:
• Purchase 35 computers to replace old equipment.
• Purchase Internet service.

Table 5.4 Scenario C

Stage	Computer cost	Networks within schools	Networks between schools	Internet	Total
1	$70,400	$20,300	$0	$4,500	$95,200
2	$77,440	$15,930	$15,000	$6,000	$114,370
3	$48,710	$33,500	$9,300	$6,000	$97,300
4	$65,710	$36,500	$10,800	$6,000	$118,000
5	$108,720	$29,500	$5,600	$6,000	$150,000
Ongoing annual	$103,800	$11,500	$3,320	$6,000	$125,000

Source: MIT TPP91, p. 24.

* Number of computers would reach 243. There would be 75 in the high school, 30 in the junior high school, and 138 in elementary school classrooms.

In this high-level scenario, nearly 250 computers would be connected to each other and the Internet, with a student to computer ratio of 17:1. Unlike the second scenario, all five high school labs are connected, and each elementary is outfitted with file server.

With the addition of more computers and network connections, maintenance costs make up much of the total expenditure. By having to replace one-seventh of all the computers annually, the town is committing nearly $80,000 each year for computers and another $50,000 in ongoing costs even after the deployment is completed. Further, support costs (not included above) could add as much as 30% to the overall budget by having to staff more professionals for curriculum development and teacher training.

5.4 Cost Factors Influencing Diffusion

• Whether the technology plan accounts for ongoing costs will influence ultimate usefulness of the technology infrastructure.

• The planned deployment of computers, as the dominant cost, will influence the ultimate use of the network.

• In the absence of a reversible strategy for technology deployment, whether implementation is staged over time will influence acceptance of the technology plan.

6 FACTORS AFFECTING EDUCATION NETWORK DIFFUSION IN ARLINGTON, MA

6.1 National Issues for Diffusion of Network Technology in Education

In 1993, President Clinton announced the formation of the National Information Infrastructure Advisory Council (NIIAC) to investigate and make recommendations for the so-called National Information Infrastructure, the Clinton administration's vision for a communications network equivalent of the highway system.[74] From that Council emerged a report called "Kickstart Initiative: Connecting America's Communities to the Information Superhighway." That report set out the Council's recommendations to the President for a nation-wide strategy of deploying a modern telecommunications infrastructure to America's neighborhoods.[75]

Based upon public hearings and commissioned studies, the Council recommended that the deployment of the national information infrastructure would be "most rapidly accomplished through connecting schools, libraries, and community centers."[76] Thus, schools and other community institutions have become the focal point for federal policy regarding the nation's telecommunications infrastructure. That policy statement itself, however, does not provide funding for the deployment of computer networks in schools. Instead, federal policy has thus far consisted of calling for private sector investment, suggesting that schools make computers and networks a priority, and providing information from the experience of other school districts.

Although the national policy articulated in the NIIAC report may not provide direct assistance for Arlington, the information gathered by the NIIAC on the experience of other school districts does highlight several lessons for success:

- Leadership: "Every successful community effort has a champion - an energetic, visionary individual who gathers wider leadership support from various sectors of the community."[77]

---

[74] National Information Infrastructure Advisory Council, "Commonground: Fundamental Principles for the National Information Infrastructure." Washington, DC: NIIAC, March 1995.
[75] United States Advisory Council on the National Information Infrastructure, "Kickstart Initiative: Connecting America's Communities to the Information Superhighway." Washington, DC: NIIAC, 1996, p. 4.
[76] NIIAC, "Kickstart," p. 5.
[77] NIIAC, "Kickstart," p. 23.

• Technology: "[S]uccessful initiatives evolved through several phases - beginning with a standalone computer with communications capabilities and standalone video players and television sets and growing into full-fledged local area and wide area networks. As their goals and needs evolve, so do their technology choices."[78]

• Training and professional development: "Unless teachers are properly trained, the technology and connections that so many are working to bring into schools, libraries, communities, and other settings will not be used to their fullest potential, or worse yet, left in the corner to gather dust."[79]

• Content: "Every Superhighway success story involves having, creating, and integrating content in a way that encourages children to learn, makes everyday tasks easier and quicker, helps people communicate faster and more frequently, and makes life more enjoyable and interesting."[80]

The experiences of other school districts, as analyzed by the NIIAC, provide insights similar to those gained from experiences with past educational technologies, and from diffusion of innovations theory. The recommendation for a "phased" approach to technology deployment echoes the suggestion from diffusion theory for a reversible and divisible technology strategy. Similarly, the recommendation for training and professional development responds to the historically demonstrated need to address the constrained situation of teachers.

However, the council's recommendation to focus on content that makes education "easier and quicker...faster..." runs contrary to the insights gained from the history of education reform. The historical emphasis on a "factory" model of education and the historical failure of educational technologies suggest that, despite the Council's findings, efficiency should not be the sole motivating force for using technology. Networked computers should not be advocated simply as a better and faster tool, but rather as a tool similar to already familiar teaching practices. Historical experience and the council's own case studies suggest that arguments about efficiency alone will not change behavior, but that personal experience and familiarity with the technology will.

[78] NIIAC, "Kickstart," p. 25.
[79] NIIAC, "Kickstart," p. 28.
[80] NIIAC, "Kickstart," p. 30.

Nevertheless, the NIIAC report on other communities' experiences does provide a unique insight on the importance of leadership. The best plans, the largest budgets, the most horizontal organizations, and the broadest community vision are insufficient for successful implementation. Dedicated leadership is necessary to make the plans, to win the funding, to streamline the organization, and to broaden the vision.

6.2 State Issues for Diffusion of Network Technology in Education

Massachusetts, like several other states, has deployed an operational state-wide "instructional telecomputing network."[81] The Massachusetts instructional network, Mass Ed Online LearnNet (MEOL), provides a state-wide computer network for schools systems which subscribe to the Massachusetts Corporation for Educational Telecommunications (MCET). The primary focus of MCET is a satellite television distance learning network, the LearnPike.

MCET has achieved a significant diffusion of its LearnPike services, with 85% of Massachusetts school districts subscribing. LearnPike subscribers are eligible to join the LearnNet, which provides members with registration services for distance learning programs, electronic conferences, electronic mail, and access to the Internet. In the past several years, however, use of MCET's distance learning LearnPike has declined, while use of MCET's computer network LearnNet has increased dramatically. In only its second year of operation, "demand for service outstripped capacity."[82]

Based on the growth in demand for computer-oriented services, and the decline in demand for broadcast distance learning services, it appears that Massachusetts made an unfortunate choice for the backbone of its educational network. Satellite networks are not the best technology for two-way interactive data communications: satellite communications have a limited bandwidth compared to fiber optics, are usually one-way, and have significant communication delays.

A better strategy may be seen in the example of North Carolina, which is in the process of deploying the North Carolina Information Highway (NCIH). Like Massachusetts, North Carolina intended to provide distance learning services to its rural school districts

---

[81]Educorp Consultants Corp., cited by OTA, p. 115.
[82]Massachusetts Corporation for Educational Telecommunications, Annual Report 1994, Cambridge, MA: MCET, 1994, p. 11.

over the statewide network. Unlike Massachusetts, however, North Carolina broadened its base of users to include government, law enforcement, health care providers, and businesses, in addition to education. Unlike Massachusetts, North Carolina selected a technology - fiber optic networks using asynchronous transfer mode switches (a high speed network system designed to handle together what Massachusetts' LearnPike and LearnNet do separately.) Unlike Massachusetts, which is purchasing satellite transponder time and borrowing computer network capacity from other state institutions, North Carolina called upon the private sector to deploy integrated network and offered the state government as the primary customer.[83]

Another, slightly different strategy can be found in the case of Iowa. Like North Carolina and unlike Massachusetts, Iowa is developing a high capacity, multi-purpose state network. Unlike North Carolina, however, Iowa contracted the deployment of its network, with the state government planning to own and operate the network itself.

Both cases, however, highlight the difficulty faced by Massachusetts. Where other states developed a broader vision for an integrated, state-wide educational network, Massachusetts committed to a single-use educational network which has become less useful and less appropriate.

One key policy influencing the deployment of educational technology in Massachusetts, however, is a state bond issue which subsidizes infrastructure renovations of school buildings. As school districts such as Arlington develop plans for renovation, they have a unique opportunity to leverage their local funds for investment in technology.

6.3 Arlington: Technology in Place[84]

The community of Arlington is in the midst of developing a long term strategic plan for the entire town. This process of developing a vision for Arlington began in 1990 with the formation of the *Vision 2020 Committee*, bringing together hundreds of stake-holders from town government, education, business, and the community at large to develop a broad outline of Arlington's long-term goals. One of the results of that effort is a long

[83]NIIAC, "Kickstart," pp. 71-72.
[84]As of May 1995, MIT TPP91, pp. 3-5.

term plan to renovate all the buildings in the Arlington School district.[85] This places Arlington in a unique position to consider issues of deploying technological infrastructure in the schools. A brief description of the current availability and use of computer networks in Arlington follows:

At first glance, educational technology seems readily available in Arlington. For example, two computer labs are visible immediately upon entering the High School. However, most of the computers in these labs are over ten years old and cannot run modern software such as Windows or easily be interconnected to a network.

In terms of networks, Arlington currently subscribes to Mass Ed Online. Membership is limited to three dial-up accounts at each school building, including three district-wide accounts. Access is limited by the availability of phone lines, in most cases in administrative areas or libraries. In addition, Arlington has an institutional cable network linking every school, operated by the local cable television service provider Continental Cablevision. Currently, this cable network is only available for use with programming from the Massachusetts Corporation for Educational Telecommunications (MCET).

In terms of Internet access, there are a limited number of accounts for individual educators through commercial services such as America Online, or through the Mass Ed Online project sponsored by MCET. Individual workstations are connected to the Internet at the elementary, middle, and high school levels. However, the Internet is not yet widely used by most teachers and students.

6.4 Arlington: Plans 1993-1998

The Arlington Public School district is in the process of developing a technology plan for deploying computer networks in all of its schools. This plan is part of a larger community effort involving education, businesses, town government, and community members. Based on interviews with key decision-makers in the school district,[86] Arlington's technology plan includes the following:

---

[85]Education Task Group, Arlington Vision 2020 Committee, Town of Arlington, "Decision '93: Upgrading our school facilities." Arlington, MA: Arlington, 1993.
[86]To protect confidentiality, information from a specific interviewee will be attributed by code. See appendix for a list of contacts.

- Incorporation of the school technology plan into the town's strategic plan.

- Staged deployment of computer networks inside school buildings: local school networks will be implemented as each school is renovated in turn. Budgets for deploying computers and networks as part of the renovation process have been approved by the school committee for some locations.

- Expected state reimbursement of 63% of the renovation costs in Arlington.

- A high-level scenario for computers and networks: placing a computer and a network connection in each classroom. In the high school, a lab of networked computers is also planned.

- Placement of computers on mobile stands, providing for flexible arrangement of multiple computers or individual use.

- Use of a coaxial cable network, operated by the local cable service provider, Continental Cablevision, as a data network between schools.

- Access to the Internet, provided by a commercial Internet Service Provider via the coaxial cable network, subsidized for a period of time by Continental Cablevision.

- Technology aids in each elementary school for transitional professional development.

- Formation of a technology committee for the district to plan implementation, and to act as advisory committee on future technology choices.

- Formation of a staff position to coordinate computer network development throughout the district.

- Changing the high school schedule to a block schedule, in part to facilitate the use of technology and the visibility of its benefits.

6.5 Arlington: Evaluation of Factors

6.5.1 Summary of Factors

The examination of the historical cycle of educational technologies, historical approaches to education reform, diffusion of innovations theory, specific cost models for Arlington, and the NIIAC report has identified several factors that are expected to influence the success of Arlington's strategy for network deployment.

Table 6.1 Diffusion Model: Factors and Stages

	Diffusion			Stages	
Factors	**Knowledge**	**Attitude Formation**	**Decision**	**Implement.**	**Sustained Implement.**
Educational Technology					
Incentives				+	
Professional Dev.					+
Impact on Role					+ / -
Education Reform					
Uniquely Education		+			
Non-Economic		+			
Multiple Use					+
Scope of Support			+	+	
Diffusion Theory					
Efficiency		+			
Communicability	+				
Compatibility		+			
Advantage			+		
Reversibility		+			
Divisibility		+			
Complexity		-			
Commitment			-		
Gatekeepers	-				
Origin	+ / -				
Terminality				+ / -	
Cost Models					
Ongoing Costs					+ / -
Deploy Computers				+	
Stage Implement				+	
NIIAC					
Leadership		+			

For the *knowledge* stage, the most important factors are postulated to be **communicability**, **gatekeepers**, and **point of origin**. For the *attitude formation* stage, the most important factors are postulated to be the presence of a **unique concept for educational use**, **non-economic motivations** for adoption, and **leadership**. For the *decision* stage, the most important factors are postulated to be **scope of support**, **perceived relative advantage**, **cost**, and **commitment**. For the *implementation* stage, the most important factors are postulated to be **incentives for innovative behavior**, **scope of support**, **terminality**, **planned deployment of computers**, and the use of a **staged implementation** plan. For the *sustained implementation* stage, the most important factors are postulated to be **time and resources for professional development**, **impact on classroom role of teacher**, **multiple forms of use**, and **treatment of ongoing costs**.[87]

The factors postulated to have a positive impact on diffusion are **incentives for innovation**, **professional development**, **unique concept for education**, **non-economic motivations**, **multiple forms of use**, **scope of support**, **efficiency**, **communicability**, **compatibility**, **relative advantage**, **reversibility**, **divisibility**, **deployment of computers**, **staged implementation**, and **leadership**. The factors postulated to have a negative impact are **complexity**, **commitment**, and **gatekeepers**. The factors that may have either a positive or negative impact are **impact on classroom role**, **point of origin**, **terminality**, and **ongoing costs**. Further research is required to verify the direction and mechanisms of influence for these factors.

The diffusion of computer networks in Arlington should be successful to the extent that Arlington's plans for network deployment addresses these factors - taking advantage of the positive and ameliorating the impact of the negative. An evaluation of Arlington's strategy with respect to each factor is given below.

6.5.2 Incentives for Innovative Behavior

Currently, no formal system of incentives has been tied to teacher or student use of technology. Although tying incentives to teacher use of technology can influence teacher adoption, the negotiation and implementation of a formal system might prove difficult. For Arlington, which has recently faced a teacher "work-to-rule" action over contract

[87]See section 4.3 for a discussion of the influence of such factors on the diffusion process.

negotiations, an informal incentive system may be simpler, although the impact on teacher behavior would be less clear.

In the future, Arlington may develop an incentive system for teachers and students to innovate. At the moment, however, this factor is absent.

6.5.3 Time and Resources for Professional Development

Currently, the professional development is provided by the high school media center staff, the district libraries staff, and six part-time technology aids based in the elementary schools. In addition, a coordinating position for technology is being formed, pending funding.

Some training at the elementary schools is done on a one-on-one basis, with a substitute taking over a teacher's class for the training period. In addition, some workshops and after schools training sessions have been conducted.

The availability of time and resources, however, is limited by several factors. First, the availability of substitutes depends upon the schedule and budget of the given school at the time. Second, the interest of teachers in participating in staff development varies from individual to individual, and is often limited by the time available to teachers to gain experience with the technology. Third, training sessions are often restricted to a one-on-one format at the elementary schools because what technology is available has been placed in isolation in classrooms. While some teachers have been willing to move their computers into a lab setting for workshops, the technology in the classroom seems to remain in the classroom.[88]

In the future, it is unclear whether funding for the technology aids will continue, whether more resources for professional development will become available, or whether teacher interest in training will increase. At the moment, however, Arlington's strategy does include this factor.

[88]Based on interviews (code 9604032).

6.5.4 Impact on Classroom Role

The impact of networked computers on the teacher's role in the classroom is difficult to evaluate. Comments from educators in other districts using networked computers include claims that teachers become "guides and coaches" rather than lecturers."[89] In Arlington, however, networked computers for education have been used for email communication between teachers, email between classes, curriculum units developed by organizations such as the National Geographic Kids Network, and for class research.[90]

In the future, the potential may exist for networked computers to influence the role of Arlington's teachers in the classroom. At the moment, however, the available examples of use suggest little to no impact on the classroom role of teachers in Arlington.

6.5.5 Unique Concept for Educational Use

The justification for deploying networks in Arlington includes efficiency and time savings, similar to industry motivations for developing advanced telecommunications capabilities. Also, some current uses of networked computers in Arlington - email and research - also parallel industry uses of telecommunications.

One distinctly educational use of networked computers in Arlington, however, involves curricular projects developed by organizations such as the Smithsonian.[91] Other districts are also using networked computers for collaborative educational projects and for bringing external expertise into the classroom.

A unique concept for educational use of networked computers in Arlington appears to be developing, but primary motivations still arise from the example of business.

6.5.6 Non-Economic Motivations

Beyond the motivation for increased efficiency and savings of time, computer networks in Arlington are also perceived to have non-economic benefits. Staff comments about computer networks cite the quantity of information available from the Internet, implying a

---

[89]NIIAC, "Kickstart," p. 13.
[90]Based on interviews (code 9619072).
[91]Based on interviews (code 9619072).

perception of computer networks as a means to access an educational resource, similar to going to a library to conduct research.

Also, current usage of email communication and externally-organized curricular projects suggest a model of using networked computers for enrichment, not just to enhance efficiency. Thus, even with the limited deployment in Arlington, this factor is already present.

6.5.7 Multiple Forms of Use

The main sense in which Arlington has planned for multiple forms of use has been the deployment of networked computers on mobile carts. This provides some flexibility for using individual computers in the classroom, or bringing several computers together to form a lab setting. However, initial reports of actual movement of computers suggest that this option, although available, has been used sparingly. Whether that will continue in the future is unclear, but current experience suggests that Arlington has effectively committed itself to a strategy of individual units in classrooms.

6.5.8 Scope of Support

As an economically developed suburb, the population of Arlington is significantly wealthier (+$4000 per capita income), more professional (+12% employed as managers and professionals), and more highly educated (+16% with college degrees or higher) than state averages.[92] The higher-income, professional, and highly educated nature of the residents implies a greater opportunity for residents to be exposed to information technologies - at home, through their educational experiences, and in their workplaces.

Indeed, the strategic development of a broad scope of support for education in Arlington has been one of the cornerstones of Arlington's technology strategy. According to interviewed sources, the change in demographics from predominantly "blue-collar" to more "white-collar" residents in recent years has made it possible to draw out a vocal, politically active group of non-parent residents to support the schools. That support is

[92]Hornor, E., ed. Massachusetts Municipal Profiles 1994-95. Palo Alto, CA: Information Publications, 1994, p. 359; Commonwealth of Massachusetts, Executive Office of Education. Greater Boston Region School District Profiles. Boston: Parent Information Center, 1993, p. District 010; Commonwealth of Massachusetts, Executive Office of Communities and Development. "Arlington, Middlesex County: A Community Profile 1993." Boston: EOCD, 1993, pp. 5-6.

critical in a community where only ~18% of residents have children in the Arlington public school system.[93]

Beyond seeking residential support, however, Arlington has cultivated business support for a long range vision for Arlington in general and for Arlington's schools in particular. One significant mark of the success of that strategy has been the involvement of the local cable service provider, Continental Cablevision, in Arlington's plans to network the schools. Although discussions are still underway, it appears that Continental Cablevision will play a significant role in providing Internet access for Arlington's schools, and for the operation of Arlington's district-wide network.

Within the schools, support for educational technology varies from school to school and teacher to teacher. In many cases, key teachers and administrators have taken leadership in using and lobbying for technology in the schools.

Within the town government, support for educational technology has extended beyond the school committee to town administrators and critical funding committees.[94] In general, wide-spread community support has been actively sought and developed in Arlington, with its Vision 2020 committee and strategic planning town forums.

6.5.9 Financial Returns / Efficiency

Although it is difficult to quantitatively estimate the financial returns or efficiency gains due to networked computers in the Arlington school system, it is clear that such benefits are perceived to exist. Most interviewees mentioned some concept of efficiency in relation to networked computers, although some acknowledged the considerable time required to learn how to use a new technology.[95]

One person suggested that technology could make it possible to achieve in one hour what normally would take one day to accomplish.[96] Another said that efficiency was a primary

---

[93]Based on interviews (code 9619076).
[94]Buchanan, L. "Bilafer: No delays expected for middle school renovation," Arlington Advocate. April 25, 1996, p. 1.
[95]Based on interviews (code 9604032).
[96]Based on interviews (code 9611046).

argument used to attract teachers to training sessions.[97] In general, networked computers are clearly perceived as being beneficial in terms of professional efficiency.

6.5.10 Communicability

Since current use of networked computers in Arlington is limited, communicability is difficult to evaluate. However, the planned change in the high school to block scheduling was partly motivated by a desire to facilitate use of technology in the high school, and to increase the visibility of its results. This planned structural change indicates some consideration in Arlington of the need to disseminate information about innovative uses of technology.[98]

6.5.11 Compatibility

The adoption of computer networks in the Arlington schools appears to be compatible with the goals and values of the town's decision-makers, but not all decision-makers in Arlington consider educational technology a priority for funding. Even supporters of computer networks acknowledge that the bulk of the opposition comes from a different opinion of how to allocated limited resources, not from a difference in opinion on serving the best interests of the children.[99] Thus, supporters rely on the common organizational value of serving the children's best interests when arguing for the funding of computer networks in the Arlington schools.

6.5.12 Perceived Relative Advantage

As mentioned before, networked computers are not necessarily seen as a replacement for current educational practice, but rather as an enrichment of current practice. Therefore, the perceived relative advantage of using networked computers over traditional teaching methods is limited. For example, students in the high school library are said to use the Internet as a research tool of last resort, after other traditional research methods have been

[97] Based on interviews (code 9604031).
[98] Based on interviews (code 9611041).
[99] Based on interviews (code 9611047).

used.[100] On the other hand, administrators perceive significant advantages of using networked computers, again mostly in terms of saving time.[101]

6.5.13 Reversibility

Unfortunately, because Arlington has unified its deployment of technology with a master renovation plan and because of the nature of capital investments, implementation appears to be irreversible. The deployment of hardware will be part of the planned renovations of Arlington's school buildings over the next decade; the investment in infrastructure, once completed, cannot be undone. Indeed, it is difficult to imagine any capital investment strategy that might be "reversible" in this sense. In the absence of reversibility, however, implementation can still be staged over time (see below).

6.5.14 Divisibility

In this case, although the technology implementation strategy has been unified with the renovation plan, the deployment of computer networks remains a divisible process. The planned renovations of Arlington's school buildings is staged building by building, providing an automatic means of dividing implementation of networked computers. After one building is renovated incorporating a particular network technology, a different technology choice or level of investment can be selected for the next building. This avoids requiring a massive commitment of significant resources at the outset, which could become a major obstacle to successful diffusion.

6.5.15 Complexity

One recurring criticism of educational technologies involves the complexity for the teacher attempting to use the machines. The same, unfortunately, is true of networked computers. Interviewees have commented on some teachers' understanding of technology as a black box, and the teachers' fear of "breaking" it.[102] At the same time, like most educational technologies of the past, networked computers were not explicitly designed for teachers, and some non-trivial learning is required. As one put it, some teachers know that the technology is capable of doing something, but must learn other

---

[100] Based on interviews (code 9619074).
[101] Based on interviews (code 9610131).
[102] Based on interviews (code 9611045).

fundamental technology skills first.[103] Complexity is a factor in the deployment of computer networks, but Arlington is making an effort to provide training and support (see above).

6.5.16 Commitment

The strategic manipulation of this factor is one of the cornerstones of Arlington's strategy. By tying the deployment of computer networks with state-reimbursed building renovations, Arlington is leveraging its own limited financial resources and reducing significantly the initial capital commitment required to wire the district's classrooms. The state bond issue funding 63% of school renovation costs drastically reduces the effective cost faced by Arlington for implementing its technology plan. This strategy of minimizing the commitment of resources, linked with a strategic manipulation of terminality (see below), has proven effective thus far in gaining the support of the town to fund computer networks.

6.5.17 Gatekeepers

The presence of numerous gatekeepers in educational organizations has always been a problem for educational technology, and unfortunately, the same is true for networked computers in Arlington. Although the community, school board, and school administration all appear to support computer networks in Arlington, the key gatekeepers in Arlington are the teachers. For the use of networked computers, teacher reaction has been mixed, from innovative use to explicit fear.[104] The influence of the gatekeeping factor has been exacerbated in Arlington by the decision to place individual networked computers in classrooms, instead of groups of networked computers in a school lab. With each teacher effectively controlling access to the particular machine in his / her classroom, use has varied and will probably continue to vary widely. One possible argument for placing computers under the direct control of each teacher is to enhance the teacher's sense of ownership which may then facilitate use. The results thus far indicate mixed success - some teachers have taken computers home to gain more experience and familiarity, while others simply treat computers as just another "station" to send their students to when extra time is available in class.[105]

---

[103]Based on interviews (code 9604031).
[104]Based on interviews (code 9619072).
[105]Based on interviews (code 9604032).

6.5.18 Point of Origin

This particular factor is especially difficult to evaluate for Arlington. While it is true that the superintendent, in beginning her tenure nearly 2 years ago, made technology a priority for the Arlington school system, the exact point of origin of the discussion concerning computer networks is unclear. Independent evaluation is further complicated by a previous study co-authored by this researcher examining the technology options for computer networks in Arlington. That report, and this researcher, may have thus played a role in the origin of some of the ideas expressed in Arlington's current technology plan.

Nevertheless, even if some aspects of Arlington's network technology plan originated externally, even from previous research, those aspects have been adopted by Arlington decision-makers, and Arlington has developed other aspects internally. Furthermore, although such external ideas may have influenced plans and may influence ultimate success, the isolated fact that certain ideas came from outside Arlington does not appear to have contributed to either a positive or negative attitude towards the technology.

6.5.19 Terminality

The manipulation of terminality, in conjunction with its effect on commitment (see above), is a key factor in the ability of advocates of computer networks in Arlington to gain community approval and town funding for their plans. Terminality refers to the time available for decision-making after which implementation is impossible or undesirable. Given the fact that 63% of the costs of school infrastructure renovations are reimbursed by the state, the question faced by Arlington is, "Do you want to pay 37 cents now, or the full dollar later?"[106] Thus, decision-makers and the community are faced with a terminal decision point: approval of the technology plan before that terminal point (completed renovation of the schools) requires a significant commitment of resources, but approval after that terminal point requires nearly three times the commitment of resources for the same capabilities.[107] The strategy thus far has resulted in approval and commitment of funds.

[106]Based on interviews (code 9611047).

[107]This author makes no evaluation regarding decision-makers' implicit lack of understanding of rapidly declining costs of telecommunications technology given the success of this strategy. Regardless, the strategic use of terminality has been successful in Arlington thus far.

6.5.20 Ongoing Costs

One negative implication of a unified strategy for network deployment (combining network deployment with general renovation) is that the technology investment is seen as a one-time, large-scale, capital investment. Thus, the ongoing commitment of resources to repair and replace equipment may not correspond to the initial commitment level of resources to deploy the original infrastructure. This approach, and the corresponding deflection of attention away from ongoing costs, has negative implications for the long-term success of computer networks in Arlington. Another possible reason for less attention to ongoing costs (besides the difficulty in calling for additional commitment of resources) is the inability to foresee the long term need or use of the network. However, even if it is acknowledged that Arlington "may not need the wiring in five years," it is argued that students "need" to be "competitive" now, and that technology is important for that need.[108]

6.5.21 Deployment of Computers

Most educational uses of telecommunications involve computers (perhaps phone calls and fax machines are exceptions). Thus, the effective use of networks in Arlington depends significantly on the deployment of computers. Presently, Arlington is in the midst of a 4 year computer technology plan calling for the placement of computers in every classroom. However, actual implementation has faced difficulties, as some have observed that after two years, Arlington had not yet finished the first year of its computer plan.[109] The successful implementation of networks in Arlington is clearly contingent on the successful completion of plans to implement computers in Arlington.

6.5.22 Staged Implementation

Since the deployment of computer networks in education is not a reversible investment, a compensatory strategy would be to stage implementation over time. Each stage, then, would represent an irreversible investment of resources, but the remaining stages could be modified or even canceled after an evaluation at a prior stage. In Arlington, the staged implementation over time is similar to divisibility: school buildings are renovated and networked individually, finished at one location before being initiated at another.

---

[108] Based on interviews, (code 9611047).
[109] Based on interviews, (code 9604032).

As in the strategy of divisibility (see above), this strategy provides opportunities to evaluate the success of implementation at one school before applying that technology at another. However, this staging strategy assumes that schools are similar enough to each other that the causes of success or failure at one can be used to prepare a better strategy for the next. A different staging strategy would be to implement local area networks first, then a district-wide network, and finally Internet access. Nevertheless, Arlington does plan to stage implementation over time.

6.5.23 Leadership

Finally, a factor for success in Arlington has been leadership, not only in terms of implementing technology in the schools, but also in terms of gaining external community support for the schools. As discussed in the national context above, leadership plays a significant role in the success of communities seeking to join the NII. In this case, the superintendent is cited by many as a major leader in making both implementation of networks and fiscal credibility of the schools priorities.[110]

One mark of that leadership has been the school budget itself. In the face of stagnant town budgets, school budgets have increased slowly but steadily, making up nearly 30% of the town budget in fiscal year 1995.[111] In addition, incorporating technology has become a priority. Under the tenure of the previous superintendent, educational technology in general and telecommunications in particular were barely mentioned in the long-range plans for renovating every school building. The fact that those plans were revised midstream to include wiring for local area networks inside the schools indicates active leadership in changing past plans to reflect current priorities.

6.6 Arlington: Prospects for Success

From the evaluation of the factors for Arlington above, it appears that Arlington's technology strategy addresses 12 of the 15 positive factors (professional development, unique concept for education, non-economic motivations, multiple forms of use, scope of support, financial returns / efficiency, communicability, compatibility, divisibility,

---

[110]Based on interviews, (code 9619076).
[111]Town of Arlington, Massachusetts. 1992 Annual Report, 1993 Annual Report, 1994 Annual Report. Arlington, MA: Arlington, 1993, 1994, 1995, Financial Management Services section.

deployment of computers, staged implementation, and leadership), and arguably the most significant of the 3 negative factors (commitment). For the four other factors that could be positive or negative, Arlington's strategy uses terminality positively, has difficulty with ongoing costs, and does not appear to be affected by the other two.

In general, Arlington's unified approach - bringing together the different stake-holders in the decision-making process and linking technology deployment with planned infrastructure renovations - emphasizes the positive impact of wide scope of support and minimizes the negative impact of the commitment required to put technology in place.

Additional factors, including a staged renovation plan, provision for some professional development, and strong leadership also argue for a successful deployment of computer networks in the Arlington school system.

However, Arlington will also face several challenges in the future, some inherent to the process of educational innovation, but some also due to Arlington's particular strategy:

- Ongoing costs will be a significant challenge for Arlington. Expenditures to repair and replace equipment will not be reimbursed by the state at 63%, and Arlington's commitment to modern technology in its schools may become clear when it is asked to pay for 100% of the ongoing costs involved in its technology plan.

- Even if deployment is successful, teachers are still the key to successful use. Some system of encouraging innovative behavior in teachers should be adopted. Professional development should be a priority, and the decision to place computers in classrooms rather than labs may need to be re-evaluated. More consideration and investigation should be made of the impact on the classroom role of teachers. Channels of communication should be established to make success stories visible, and to offer teachers examples of what is possible with the technology. Ultimately, Arlington must recognize the teacher's fundamental role as the gatekeeper.

- Finally, technology in the Arlington school system must continue to be made a priority for the entire community. While Arlington may benefit from current leadership for now, the long-term quality of Arlington's schools depends on the success of not just Arlington's technology strategy, but also of Arlington's commitment to a broad-based, unified vision for the entire community.

7 BEYOND ARLINGTON

7.1 Policy Issues

Clearly, the successful diffusion of innovations in education is much more complex than simply identifying the financial costs and benefits. The examination of the historical cycle of educational technologies, historical approaches to education reform, and diffusion of innovations theory indicate that a successful technology strategy must address much more than just *what can it do?* and *how much will it cost?* Yet beyond the recommendations for other school districts, several policy issues should also be addressed by state and national policy-makers. Furthermore, some fundamental questions remain for future research.

7.1.1 Other Districts

The deployment of computer networks in Arlington raises several policy concerns for other school districts seeking to implement computer networks.

- Arlington's technology strategy relies upon developing a unified vision in the community.

Arlington seems to have been successful in creating a community-wide vision for technology in its schools. Arlington's success, however, raises the question of whether other communities can be successful in developing a similarly unified vision for their schools. How does a community develop such a unified vision? Clearly, simply creating a "Vision 2020" committee is insufficient; developing a unified vision is a process that may be even more complex than the diffusion of innovations. Nevertheless, Arlington's example does offer some suggestions for other districts.

It seems clear that some organizational structure is necessary for bringing together different stakeholders in the process. Whether a new structure is created or an existing one is expanded, some form of a "Vision 2020" committee provides a useful forum for the discussion, negotiation, and persuasion required to develop a shared vision in the community.

- Arlington has developed that vision by broadening the representation of different stakeholders and interests in the planning process.

At first glance, this policy seems to be useful for developing a broad scope of support once a shared vision has been developed. Businesses are more likely to contribute to funding technology in the schools, for example, if they share some control in the planning process. Teachers are more likely to accept a new educational technology if they have had input on the initial deployment decisions. As a policy, then, broadening the representation of different stakeholders in the planning process seems to be advisable for other districts.

However, broadening the scope of support comes at a cost. If more stakeholders are involved, then clearly the influence of each stakeholder is reduced. As a result, the technology deployment may not become motivated by purely educational goals, but rather by many different interests - administrative, governmental, business, residential, as well as educational. In addition, a unified approach may become more difficult to develop as more stakeholders are added to the process. As communities consider the representation of different interests in their planning process, they must evaluate the trade-off between increasing the difficulty of the process and broadening the scope of support for the outcome.

- Arlington’s technology strategy unifies network deployment with planned school renovations.

If a district is planning to install a network infrastructure in its school buildings, it makes sense to do so when those buildings are already being renovated for other purposes. Not only does this approach provide potential savings in implementation costs, it also takes advantage (in Massachusetts) of state reimbursement for school renovation costs. When school districts are planning to renovate their buildings, there is a strategic opportunity for those districts to plan also for network deployment.

However, not all districts are planning to renovate their buildings. Those schools that have already been renovated can no longer follow Arlington’s example. Those school districts that cannot afford renovations, even with significant potential reimbursement from the state, will also be unable to use Arlington’s unified approach.

• Arlington has treated network deployment as a capital investment, focusing on deployment costs.

Although investment in a computer network infrastructure clearly seems to be a capital investment, a more detailed cost analysis reveals significant ongoing costs for maintenance and replacement. Furthermore, the need to focus on professional development implicitly calls for a long term commitment to funding for teacher training and support. By treating technology in the schools as a one-time cost, a district such as Arlington might be successful in gaining the support and funding required to deploy the initial infrastructure. However, that approach may not gain the long term support and funding required to sustain the implementation and use of the network.

Other districts might use Arlington's strategy to acquire the initial equipment for their technology plans. But those districts would also do well to consider carefully the support and funding available for sustained use. It may be more effective in the long run for schools to develop their technology plans based on the long term funding available for maintenance and support, rather than the immediate funding available for initial deployment.

• Arlington has made strategic use of terminality.

One way that proponents of educational technology in Arlington have been able to gain support for funding network deployment in the schools is by using state reimbursement for renovations as a virtual deadline for acceptance. If the community adopts the technology vision before that deadline, then funds are available from the state to pay for a significant portion of the deployment costs. If the community waits beyond that deadline, however, then the community alone will bear the costs of deployment.

However, the choices presented above may not be an accurate representation of the choices faced by a community. Technology costs do not remain constant over time - for telecommunications and computer technology, performance-normalized costs have been declining rapidly. Furthermore, there is an opportunity cost associated with being on the leading edge of innovation - adopting an innovation early in the technology cycle commits the district to certain technology choices, before it becomes clear whether those choices are optimal. One example is Massachusetts' commitment to a satellite system for its state-wide educational network, only to find that broadcast television programming is being replaced with computer communications as a primary use of such networks.

Other districts, recognizing the irreversibility of infrastructure investment, may make a strategic choice to wait until later in the technology cycle. After the technology choices have become clear, costs have been driven down and initial implementation problems have been resolved by other districts. But in doing so, they should be mindful that a class of students leaves the district every year. While delaying implementation of technology may reduce costs for the district in the long run, it also denies those students access to the technology.

• Arlington must begin to look beyond initial funding to sustained implementation.

Fortunately, it appears as though some form of network infrastructure will be deployed in the Arlington school district. Having addressed those questions of deployment, however, Arlington now faces the long term issues of sustained implementation and actual teacher and student use.

Other districts, once successful in creating a strategy for deployment, will also face these issues. At that point, districts should focus on the factors influencing sustained implementation: time and resources for professional development, impact on the classroom role of the teacher, and ongoing costs. Including teachers in the planning process is the first step towards gaining teacher support for technology in the district. Unfortunately, gaining teacher acceptance of technology in the classroom is a different matter, and encouraging actual teacher use may be more difficult than acquiring the initial equipment.

Ultimately, district policy-makers must recognize that teachers are the gatekeepers for technology in the classroom. None may enter but by their permission, and none will succeed but by their acceptance. Claims by technology enthusiasts that computerized education will “revolutionize” the classroom may have merit, but as the historical cycle of educational technology has demonstrated, the institution of classroom education has a powerful influence on the impact of technology in education.

7.1.2 National and State Policies

Local school districts are not the only political entities that should address policy issues about educational technology. As Arlington's case demonstrates, both state and national policies can influence the deployment of technology in school systems.

• National policy-makers have made educational technology a visible priority.

The creation of the National Information Infrastructure Advisory Council and the subsequent emphasis on connecting schools to the information superhighway has brought educational computer networks to the attention of school districts, businesses, individuals and organizations nation-wide. That publicity in itself will contribute to the diffusion of computer networks in education, by spreading knowledge of the innovation to potential adopters.

National policy-makers have also committed to providing some funding for deployment, with the U.S. Department of Education stating that the federal contribution might be as much as $2 billion.[112] That funding, although not nearly sufficient to pay for the deployment of computer networks in all of the nation's schools, may help provide seed money for pilot projects.

• National policy-makers have changed the laws governing telecommunications regulation.

The Telecommunications Reform Act of 1996 has raised the possibility of widespread competition among telecommunications service providers for many sectors of the market, including education. That competition, in addition to the priority placed on networks for education by national policy-makers, has resulted in several initiatives by telecommunications firms to bring services to the classroom. The long-distance giant AT&T, Regional Bell Operating Companies, national cable service providers, and local cable companies have developed plans for educational networks.[113]

---

[112] Smith, M., cited by Applebome.

[113] Naik, G. "AT&T to Give 110,000 Schools Free Services; Voice Messaging, Access to Internet Will Mark Start of National Push," The Wall Street Journal. Nov 1, 1995, Sec A, p. 3.; "Technology: Bell Atlantic and TCI Plan Data Network for Schools," The Wall Street Journal. Jan 11, 1994, Sec C, p. 17.; based on interviews (code 9619071).

The long term impact of the Act and the long term commitment of telecommunications service providers to educational networks remain unclear. But if telecommunications companies view education as a strategic market for services, as Apple has for personal computers, local schools may benefit from the national policy allowing competition among such firms.

• The national priority of deploying network infrastructure in schools is partly motivated by a national goal for universal access.

As *universal service* has become replaced by *universal access* in the telecommunications lexicon of national policy-makers, schools have become a focal point for the national strategy to ensure equitable access to telecommunications services. But focusing on network deployment in schools merely raises the problem to a slightly more aggregate level - no longer a question of rich and poor families, it becomes of question of rich and poor school districts or rich and poor states. If districts are left to themselves, without external support for their initiatives or external pressure on the private sector to provide access, wealthier districts are likely to be more successful than poorer ones in implementing educational technology.

The recent Telecommunications Reform Act of 1996 does mandate preferential service rates for educational institutions, but it remains unclear whether that mandate will be sufficient to allow disadvantaged school districts to join the so-called information superhighway.

• Massachusetts has invested in a state-wide educational network.

Massachusetts' investment in a state-wide educational network demonstrates both the possibilities and the pitfalls of heavy state involvement in such networks. While the state effort has resulted in significant deployment of infrastructure in its public schools,[114] Massachusetts has also committed itself to a technology choice poorly suited for interactive computer networks. While states can do a great deal to place technology in the schools, as North Carolina and Iowa are seeking to do, they also increase the scope and level of commitment. Whether other states' strategies prove more successful than

[114]MCET, p. 11.

Massachusetts remains to be seen, but local schools may continue to benefit from such state initiatives.

• Massachusetts provides funds to reimburse school districts for building renovations.

A more expensive, but possibly more effective state policy has been to help defray the costs of local deployment. Creating a single state network for all local districts may take advantage of economies of scale, but providing funding to local districts for community-based initiatives may encourage more local innovation and reduce the state-wide commitment to any single technology choice. Arlington has been able to take advantage of state reimbursement for building renovations, but state policies specifically funding technology deployment may be more effective for other school districts.

State governments may also seek to develop a unified approach to educational networks, increasing the participation of different stakeholders in the diffusion process. But as in the case of a community-based unified approach, there is a trade-off between broadening the scope of support and increasing the difficulty of the process. Furthermore, the required commitment in resources increases dramatically for a state-wide network, an increase that may not be justified by the increased support for education.

7.1.3 Future Research

Beyond the policies for implementation, several fundamental questions should be addressed by future research.

• Many factors influencing the diffusion process have been identified, but the specific mechanisms by which those factors influence the process at different stages remains unclear.

Past research on the diffusion of innovations in education has identified several factors influencing the success of diffusion, and postulated several mechanisms by which those factors impact the process. Generalizing from various case studies and historical examples, the success or failure of the diffusion of various innovations has been explained by the influence of one or more such factors in different stages of the diffusion process. In addition, the macro-level diffusion process of innovations has been well described by an S-shaped saturation curve, providing some predictive power for macro-level diffusion processes.

However, the diffusion process in an individual organization remains difficult to predict. While it may never be possible to develop a universal model that can predict the diffusion of any innovation for any organization, more research is needed to identify the interrelationships among the different factors influencing diffusion, and to verify the mechanisms by which those factors impact different stages of the diffusion process.

- Research has focused on the objective process of deploying technology in education, but little has been done to address the normative issues raised by educational technology.

Even if the objective diffusion process of innovations in education were completely understood, the normative question remains: *should* certain technologies be deployed in education? To address the normative question, more research is needed on the educational benefits of various technologies - and correspondingly, on the measurement of those benefits.

More research is also needed to understand the impact of technologies on the classroom role of teachers, not only for the sake of better predicting the diffusion process, but also for the sake of better preparing teachers and students to teach and learn in the classrooms of tomorrow. As Martha Stone Wiske, director of Harvard's Educational Technology Center, puts it, "One of the enduring difficulties about technology and education is that a lot of people think about the technology first and the education later, if at all."[115]

7.2 Conclusion

The central argument posed by this thesis is that Arlington, Massachusetts' unified approach - unifying the technology deployment process with a capital infrastructure renovation plan and creating a unified vision drawing upon broad community support - should be successful in implementing an initial network infrastructure in the district.

---

[115] Wiske, M. quoted by Applebome.

Factors influencing the successful diffusion of network technology in education were identified by an examination of the historical cycle of educational technology, historical approaches to education reform, and diffusion of innovation theory. Specific cost models for Arlington were used to further refine the analysis of the cost factors influencing the diffusion process. National and state issues impacting deployment of networks for education were examined to describe the broader context for Arlington's strategy. The factors identified were then postulated to influence the success of the innovation at different stages of the diffusion process.

An evaluation of those factors for Arlington suggested that Arlington's strategy addresses many of the positive factors, faces the negative factor of initial cost, and makes strategic use of terminality. On that basis, Arlington should be successful in its initial deployment of a network infrastructure for its schools. However, Arlington will face difficulty in addressing ongoing costs, long term teacher training and support, and continuity of its vision beyond the current community leadership.

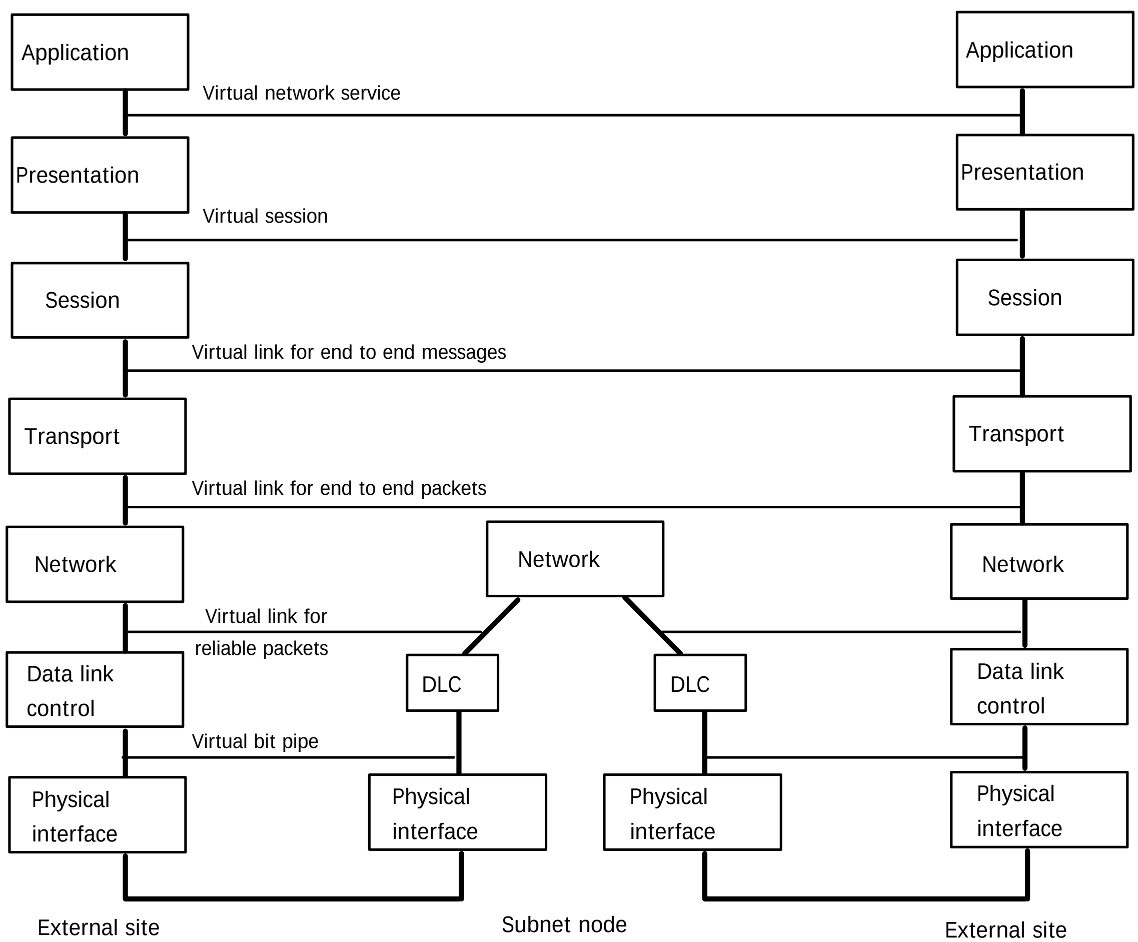
Several policy issues remain to be addressed by other districts, state and national policy-makers, and future researchers. For other districts, policy issues include creating forums to develop a unified vision, determining the extent of representation for different stakeholders in the planning process, strategically linking plans for technology deployment with plans for building renovations, planning for both initial and ongoing costs, choosing whether to adopt an innovation early or late in the technology cycle, and looking forward towards sustained use and support. For state and national policy-makers, policy issues include making educational technology a priority both in visibility and in funding, fostering competition to encourage the private sector to invest in educational technology, facilitating access for disadvantaged school districts, and balancing the economies of scale gained by state-wide networks with the benefits of local innovation gained by state reimbursement of local initiatives. For future researchers, policy issues include verifying the mechanisms by which certain factors influence different stages of the diffusion process, and addressing the normative question of the educational benefits of technology. Ultimately, policy-makers at all levels must recognize that teachers hold the keys to the classroom.

APPENDIX

Network Technology

For those who desire a technical analysis of the network technologies considered for this report, this appendix provides an in-depth discussion of various options available to the Arlington Public School System when designing an educational network. This section also explains reasons why the specific technologies used in the report's cost models were selected. For those unfamiliar with network architecture, the following figure illustrates the Open Systems Interconnection Reference Model for Computer Networks.[116]

Figure A.1 ISO / OSI Reference Model for Computer Networks



Source: Bertsekas and Gallager, p. 20.

[116]For more information on computer network architectures, see Bertsekas and Gallager, 1992.

Networks Within Schools

There are several issues that relate to computer networks within the schools. First, some of the elementary schools may be renovated in the near future, whereas the high school will not. Because the wiring might have to be replaced in the process of renovation, it would be wise to install networks in the schools which are least likely to need building improvements first.

Another consideration for installing local area networks inside the schools is what type of medium will be used. While other local area network technology have been successfully employed, the most common one in use today is Ethernet. There are several different types of wiring used in networks today, and their useful distances vary as follows:[117]

Table A.1 Network Wiring Characteristics

Network Topology	**Maximum Segment Length**
Twisted-pair Ethernet (10Base-T)	100 meters (330 feet)
Thin Ethernet (10Base-2)	185 meters (607 feet)
Thick Ethernet (10Base-5)	500 meters (1,640 feet)
Fiber-optic Ethernet	2 kilometers (6,562 feet)

Most networks are installed with high grade twisted-pair cable which is specially designed for data communications. Although twisted-pair wiring is limited in its effective distance, it offers the potential of higher bandwidths (up to 100 Mbps) by using the latest network technology. Fiber-optic cable is very useful for setting up connections between distant points and for high traffic connections. For these reasons, fiber should probably be used as the backbone for a school local area network, especially in those schools with heavier users and more computers as is the case for Arlington High School.

[117] *LAN TIMES Encyclopedia of Networking*, p.874

Networks Between Schools

Several technologies that could be used to build computer networks between Arlington schools were considered for this report. One uses a cable television network operated by Continental Cablevision, the others rely on various sorts of telecommunication services that can be leased from NYNEX.

Cable Modems on Continental Cable Institutional Network

In addition to the network that provides cable television service to Arlington, Continental Cable has installed a separate "institutional network" for the purpose of interconnecting public, educational, and governmental institutions in Arlington. This institutional network links all public schools in Arlington. By using two channels on this institutional network, the town could set up a system that would provide a high speed (10 Mbps) computer network connecting all schools. One cable modem would be placed at each school, and the modems would act as the connectors between the cable network and the local area networks within the schools. A router would be required to connect and isolate the network traffic within schools from the traffic between schools.

Such a system is used today in Lexington to provide Internet access to its public schools. Because the use of the institutional network can be negotiated as part of Continental's franchising agreement, operating these networks typically involves no monthly costs to the schools. This makes the cable option extremely attractive.

Several companies make cable modems that could be used to build a computer network between Arlington's schools. Many school systems, including Lexington's, have chosen equipment manufactured by LANCity in Andover because their systems provide a good degree of reliability and flexibility.

Leased T1 Lines

Leasing T1 lines (from NYNEX) to provide computer network connections between schools is a very expensive option due to the high monthly charges and equipment costs. Given that T1 service is only 1.54 Mbps whereas the cable network offers 10 Mbps, the cable option provides a much faster network that may cost even less than the T1 option.

Leased 56 kbps Lines

The leased 56 kbps line provides lower bandwidth and price than T1 service. However, its annual cost is still greater than ISDN or cable modems when all schools are connected to the High School. Hence, it is not recommended as an option for computer networks between schools.

Leased ISDN Lines

ISDN is a digital telephone technology that can be used with modern equipment to build computer networks. ISDN has recently received industry attention as more employees become telecommuters and more consumers demand high bandwidth access to the Internet and on-line services. Equipment is available today that can run 128 kbps connections over “basic rate” ISDN lines. ISDN service would normally be unattractive for dedicated links because of per-minute usage charges, but because all Arlington schools are serviced by one telephone company central office, Centrex ISDN service can be bought that provides connections without per-minute charges. Nonetheless, ISDN service involves monthly charges and provides much less bandwidth than the cable system can provide.

Dial-up Lines Between Schools

Some of the benefits and drawbacks of using dial-up service are explored in the following section on Internet dial-up access. This option is appealing because of its low cost, but the best modems are limited to 28.8 kbps bandwidth, a constraint that severely limits the applications that students and teachers are able to use.

Internet access

Single Computer Dial-up

Modems allow computers to communicate using ordinary voice telephone lines. Over the last few years, modem transmission rates have improved significantly while their prices have become quite affordable for computer owners. The latest modem technology—the V.34 standard—supports uncompressed bit rates of 28.8 kbps.

Modems can allow cheap and simple access to the Internet as well as to commercial on-line service providers like Prodigy, America On-Line, and CompuServe. These commercial systems offer educational tools such as current news, discussion groups, and on-line references. In an effort to enhance their products, on-line providers offer a full range of Internet services including FTP (for file transfer), electronic mail, and Gopher. Modems therefore allow inexpensive access to a wide variety of information and communication tools for education.

Teachers and administrators may benefit from the modem's ability to send and receive faxes. However, unlike most office fax machines which are used to send paper documents, modem faxes only allow users to send computer information. Nevertheless, this feature can be used to send and receive information between teachers and parents who have computers, or among teachers if they have modems but no email.

There are several drawbacks to using modems with dial-up Internet service. If the town relies on outside Internet service (instead of purchasing its own dial-up server and Internet connection), modem users will need to be aware of usage charges from on-line providers. Usage charges are troublesome because they are hard to predict for budgeting purposes and because they may discourage use. Modems further require a telephone line which may not exist in the classrooms. The increased bandwidth of today's modems has surpassed the capabilities of some older PCs that rely on slower serial ports and will therefore require additional hardware to realize their potential speed.

Although modem speeds have improved dramatically in recent years, their bandwidth is still limited for advanced uses. Modem technology has been stretched to the limit with the new models; 28.8 kbps is about as fast as modems will get. While this is more than adequate for uses such as electronic mail, it is painfully slow when browsing on the World Wide Web. The Web makes use of graphics to make it more user-friendly, but this use also places a strain on current communication technology. Thus, modems are suitable for some applications and can be an attractive low-cost option, but they will ultimately be a limiting factor on which applications the teachers and students can use.

56 kbps Dedicated Service

As an alternative to modems, which tie up a telephone line only while in use, the school system's computers can get Internet service using a special dedicated line. The bandwidth of these special lines vary from 56 kbps to 45 Mbps, but they are all conditioned by the telephone company so that they can accommodate the computer's higher data rates and lower error tolerance. Because the connection is a dedicated leased line, the services are constantly available for network access. The installation and monthly prices for Internet service from BBN, Netcom, and PSICable are included below for comparison.[118]

Table A.2 Selected Internet Service Prices

	BBN	**Netcom**	**PSICable**
Installation	$1800-4500	$750-6000	$5,000
56 kbps (per month)	$450-900/mo	$400/mo	-
1.54 Mbps (T1) (per month)	$1620-2250/mo	$1,000/mo	$2,750/mo

The Internet providers above include primary and secondary Domain Name Service (DNS) as well as different numbers of Internet addresses depending on the bandwidth of the service. For example, 56 kbps Internet service comes with about 200 hundred Internet addresses. For a fee, the providers will arrange for additional addresses if the school system needs more.

While the dedicated services are more attractive in terms of their performance, they are a more expensive option than using modems. However, the two options are not mutually exclusive. Depending on whether or not a network exists between schools, the 56 kbps service can be shared among a couple of schools. One scenario of using both leased lines and modems includes the use of modems in the junior high and elementary schools. The High School could be connected with a 56 kbps dedicated line to the Internet, and a modem pool server would be connected to this line. Elementary and junior high school computer users could then dial into this modem pool for access to the Internet.

---

[118]These prices are quotes received in the spring of 1995. They should be used for reference only, as telecommunication prices may change substantially in the future.

Alternatively, the dedicated Internet line can be shared among all of the schools. This option would allow everyone to access the Internet immediately, but as more students use the limited 56 kbps, bandwidth performance would quickly degrade. However, a similar limitation exists with the modem pool scenario: only a certain number of lines are available for use at any one time. If these lines are in use, no one else can access the Internet service. This is a major drawback for teachers who may count on access for teaching a class.

The degradation of performance as users consume the limited bandwidth would be particularly severe for advanced applications like the World Wide Web. From this viewpoint, the modem pool scenario seems attractive because it would limit the number of simultaneous users accessing the dedicated Internet line. On the other hand, the number of users may be small in the beginning, and the line can be upgraded to a faster service as demand increases.

T1 Dedicated Service

The T1 Internet service provides a bandwidth of 1.544 Mbps. The monthly cost of this service is therefore higher than the 56 kbps line service, but the performance of the Internet link would be substantially improved. Although this service would allow better performance, particularly with more simultaneous users, its cost may be inappropriate for an initial deployment before teachers and students have become familiar with the Internet.

Other Issues

Reliability

Networks are never perfect, so it is normal to expect problems to arise when using network technology. Since the Arlington school system does not have the money to lay its own wires between schools, the networks will be dependent on the wire provider to ensure quality service. NYNEX, which might provide leased lines for a network between Arlington schools, has a long tradition of offering high quality service with little down time. Using Continental’s institutional cable system for the network between schools may be less reliable than using services leased from NYNEX, but the benefits of better bandwidth at a lower cost should outweigh this as long as Continental can maintain a reasonable level of reliability.

Expansion

Different components of the school networks offer varying degrees of expandability and may affect the school system's choice of network components. Standard telephone modem technology has reached a technological maximum with 28.8 kbps, and thus it may quickly be outmoded by newer, faster communication technologies. Future cable modem systems may offer better network performance, but would require replacing equipment originally purchased for the network. Leased lines offer fixed bandwidth services with significant monthly costs, but the costs of these services may change over time, and faster services can be purchased as needs arise.

The choice of wiring inside schools is a choice between twisted pair and fiber. Twisted pair wire is less expensive than fiber, but it has distance limitations that make it less attractive. Ultimately, fiber is the most expandable wiring technology because of its potential to carry more data. But the current cost of fiber may be too high to consider using it for all of the wiring within schools. Twisted-pair wire has some promise to be useful in the near future since companies already offer upgraded 100 Mbps service. Thus, an appropriate mix of twisted pair wire for the classrooms or labs and fiber for the backbone may be the optimum wiring choice.

Cost Model Details

A certain number of assumptions were needed in order to determine approximate costs. The following table describes the prices used in the cost models.

Table A.3 Cost Model Assumptions

Item	Unit Price	Description
Server: high school	$6,000	100 MIPS computer as a network server
Server: other schools	$4,000	Similar computer with less storage
Workstation	$2,000	486 CPU with monitor, keyboard, mouse, CD-ROM
Software per computer	$200	Could include network software, word processor, spreadsheet, etc.
Printer	$1,000	300 dpi resolution laser printer
Scanner	$800	300 x 600 dpi resolution and 24 bit color
Overhead Panel	$3,500	Used to display computer screen for a class
PC Security Devices	$80	3 tie down cables and a padlock
Network Card	$100	Ethernet network interface card
Hub (per port)	$50	Based on 12 or 24 port Ethernet concentrators
Wiring to room	$350	Cost of wire, labor and hub port in closet
Wiring to closet	1100	cost of fiber, labor and hub port on backbone
Wiring per PC	$120	Cost of labor (excluding software), supplies in room
Replacement costs	10%	Annual equipment replacement costs

List of Contacts

Don Bochler, Arlington
James Brown, Technology Committee
Doug Clare, Technology Aid
Brian Clough, Arlington
Teresa DeBenidictus, Asst. Town Mngr.
Richard DeCaprio, Arlington
Antonette DiLoreto, Arlington
Kathleen Donovan, Superintendent
John Dunlap, Arlington
Jane Foley, Technology Committee
Charles Foskett, Finance Committee
Shelley Glantz, Media Specialist
Tom Hsu, Cambridge Physics Outlet
Ellie Jackson, Technology Committee
Mary Kierstead, Arlington
Doreen Killdan, Arlington
Joanne Krepelka, Cambridge DOE
Mike Leone, Continental Cable
Connie Lui, Massachusetts DOE
Bob Lynch, Technology Committee
Ted Mael, Arlington
Michael McCabe, Principal
Phil McCarthy, Arlington
Alan McClennen, Planning Committee
Helen McGah, Technology Committee
Joe Miksis, Data Processing
A.L. Minervini, Comptroller
K. Scott Nickerson, Continental Cable
Jane O’Grady, Arlington
Mary Ellen Powers, Technology Comm.

Kathleen Raphaelson, MTC
Joe Schabetti, MCET
Caroline Simmons, School Committee
Walter Stroup, Harvard ETC
Mark Wheeler, Apple Computer
Herb Yood, Technology Committee

REFERENCES

"Cable companies test Internet, school / home connections," Electronic Learning, Feb 1994, Vol. 13, No. 5, p. 6.

"Prepared Text for the President's State of the Union Message," The New York Times. Jan 24, 1996, p. 14.

"Technology: Bell Atlantic and TCI Plan Data Network for Schools," The Wall Street Journal. Jan 11, 1994, Sec C, p. 17.

Applebome, P. "Computer Idea Gets Mixed Response," The New York Times. Jan 25, 1996, p. 17.

Arlington Public Schools, Arlington, Massachusetts. "Program Budget." Arlington, MA: Arlington, 1993-1994.

Arlington Public Schools Technology Committee, Arlington, Massachusetts. "Arlington Public Schools Technology Plan." Arlington, MA: Arlington, Jun 1994.

Bertsekas, D. and Gallager, R. Data Networks, 2 ed. Englewood Cliffs, NJ: Prentice Hall, 1992.

Brown, L. Innovation Diffusion: A New Perspective. New York: Methuen, 1981.

Buchanan, L. "Bilafer: No delays expected for middle school renovation," Arlington Advocate. Apr 25, 1996, p. 1.

Bulkeley, W. "Technology (A Special Report): Back to School; Technology has the Potential to Revolutionize Education; But We Aren't There Yet," The Wall Street Journal. Nov 13, 1995, Sec R, p. 1.

Callahan, R. Education and the Cult of Efficiency. Chicago: University of Chicago Press, 1962.

Commonwealth of Massachusetts, Executive Office of Communities and Development. "Arlington, Middlesex County: A Community Profile 1993." Boston: EOCD, 1993, pp. 5-6.

Commonwealth of Massachusetts, Executive Office of Education. Greater Boston Region School District Profiles. Boston: Parent Information Center, 1993, p. District 010.

Creswell, J. Research Design. Thousand Oaks, CA: Sage Publications, 1994.

Cuban, L. Teachers and Machines: The Classroom Use of Technology Since 1920. New York: Teachers College Press, 1986.

Cuban, L. The Managerial Imperative and the Practice of Leadership in Schools. Albany, NY: State University of New York Press, 1988.

Dolan, C. “Technology (A Special Report): The Obstacles; Off Course: Although Schools Have Spent a Fortune to Buy Computers, They Still Don’t Know How to Use Them,” The Wall Street Journal. Jun 27, 1994, Sec R, p. 16.

Edosomwan, J. Integrating Innovation and Technology Management. New York: John Wiley & Sons, 1989.

Education Task Group, Arlington Vision 2020 Committee, Town of Arlington, “Decision ‘93: Upgrading our school facilities.” Arlington, MA: Arlington, 1993.

Ehrenkrantz, E. “Retrofitting in increments, redesigning your school for whatever the future may bring,” Electronic Learning, Feb 1995, Vol. 14, No. 5, p. 22

Elmore, R. and McLaughlin, M., Rand Corporation, National Institute of Education. Steady Work: Policy, Practice, and the Reform of American Education. Santa Monica, CA: Rand Corporation, Feb 1988.

Ginsburg, E. “Colleges Update Buildings for New Needs,” The New York Times. Sep 25, 1994, Sec 13NJ, p. 1.

Graham, E. “Telecommunications (A Special Report): A New World; Classrooms Without Walls: Advances in Telecommunications Promise to Transform Both Learning and Teaching,” The Wall Street Journal. May 18, 1992, Sec R, p. 8.

Gross, N., Giacquinta, J., and Bernstein, M. Implementing Organizational Innovations: A Sociological Analysis of Planned Educational Change. New York: Basic Books, Inc., 1971.

Hagedoorn, J. The Dynamic Analysis of Innovation and Diffusion. New York: Pinter Publishers, 1989.

Holzberg, C. “Open your notebooks, cheap laptops for schools for under $ 2,” Buyer’s Guide, Electronic Learning, Feb 1994, Vol. 13, No. 5, p. 26.

Hornor, E., ed. Massachusetts Municipal Profiles 1994-95. Palo Alto, CA: Information Publications, 1994.

Jackson, P. The Teacher and the Machine. Pittsburgh: University of Pittsburgh Press, 1968.

Krol, E. The Whole Internet User's Guide & Catalog. Sebastopol, CA: O'Reilly & Associates, 1992.

Lohr, S. "Computers in School: Equal Access Sought," The New York Times. Apr 27, 1994, Sec B, p. 6.

Lohr, S. "Data Highway Ignoring Poor, Study Charges," The New York Times. May 24, 1994, Sec A, p. 1.

Massachusetts Corporation for Educational Telecommunications, Annual Report 1994, Cambridge, MA: MCET, 1994.

McKnight, L. and Rothstein, R. "Technology and Cost Models of K-12 Schools on the National Information Infrastructure," submitted to Technical Horizons in Education Journal.

Moeller, B. "Collaborating online: LANs as a group learning tool," Electronic Learning, Feb 1995, Vol. 14, No. 5, p. 16.

Naik, G. "AT&T to Give 110,000 Schools Free Services; Voice Messaging, Access to Internet Will Mark Start of National Push," The Wall Street Journal. Nov 1, 1995, Sec A, p. 3.

National Information Infrastructure Advisory Council, "Commonground: Fundamental Principles for the National Information Infrastructure." Washington, DC: NIIAC, March 1995.

Perelman, L. School's Out: A Radical New Formula for the Revitalization of America's Educational System. New York: Avon Books, 1992.

Ray, G. The Diffusion of Mature Technologies. New York: Cambridge University Press, 1984.

Rogers, E. Diffusion of Innovations, 4 ed. New York: The Free Press, 1995.

Rothman, J., Erlich, J., and Teresa, J. Promoting Innovation and Change in Organizations and Communities: A Planning Manual. New York: Wiley, 1976.

Rubin, H. Qualitative Interviewing: The Art of Hearing Data. Thousand Oaks, CA: Sage Publications, 1995.

Schuster, J. "5 things you should know about districtwide networking," Electronic Learning, Feb 1995, Vol. 14, No. 5, p. 32.

Schuster, J. “The convergence of the twain: computers and fiber optics are coming together in cheap and powerful ways,” interview with Discovery Institute fellow and author George Gilder, “The Road to Utopia?”, special section, Interview. Electronic Learning, May 1994, Vol. 13, No. 8, p. 30.

Sheldon, T. LAN TIMES Encyclopedia of Networking. Berkeley, CA: Osborne McGraw-Hill, 1994.

Shaiken, H. Work Transformed: Automation and Labor in the Computer Age. New York: Holt, Rinehart and Winston, 1984.

Stoneman, P., ed. Handbook of the Economics of Innovation and Technological Change. Cambridge, MA: Blackwell, 1995.

Strekalovsky and Hoit, Inc., Architects. “Town of Arlington: School Facilities - Master Plan Study.” Arlington, MA: Strekalovsky & Hoit, Inc., Mar 1993.

Thornburg, D. “Why wait for bandwidth? Schools can teleconference, even with ordinary phone lines,” Electronic Learning, Nov 1994, Vol. 14, No. 3, p. 20.

Town of Arlington, Massachusetts. 1992 Annual Report. Arlington, MA: Arlington, 1993.

Town of Arlington, Massachusetts. 1993 Annual Report. Arlington, MA: Arlington, 1994.

Town of Arlington, Massachusetts. 1994 Annual Report. Arlington, MA: Arlington, 1995.

TPP91: Proseminar on Telecommunications Modeling and Policy Analysis, Massachusetts Institute of Technology. “Computer and Network Technology in the Arlington Public School System.” Cambridge, MA: MIT TPP, Jun 17, 1995.

Tyack, D. The One Best System: A History of American Urban Education. Cambridge, MA: Harvard University Press, 1974.

U.S. Congress, Office of Technology Assessment, Teachers and Technology: Making the Connection, OTA-EHR-616. Washington, DC: U.S. Government Printing Office, Apr 1995.

United States Advisory Council on the National Information Infrastructure, “Kickstart Initiative: Connecting America’s Communities to the Information Superhighway.” Washington, DC: NIIAC, 1996.

Valente, T. Network Models of the Diffusion of Innovations. Cresskill: NJ, 1995.

Vision 2020 Steering and Planning Committee, Arlington, Massachusetts. Report of the Vision 2020 Committee. Arlington, MA: Arlington, 1992

Winerip, M. "Classrooms on the Information Highway," The New York Times. Jul 20, 1994, Sec B, p. 7.

Zaltman, G., Duncan, R., and Holbeck, J. Innovations and Organizations. Malabar, FL: Robert E. Krieger Publishing Company, 1984.