

Research Monograph No. 22

Analysis of Education Information Systems In the Context of Systemic Reform

Christopher A. Thorn, Jeffery Watson, & Susan Zeyher



Funded by the
National Science Foundation

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The research reported in this paper was supported by a cooperative agreement between the National Science Foundation and the University of Wisconsin–Madison (Cooperative Agreement No. RED-9452971). At UW–Madison, the National Institute for Science Education is housed in the Wisconsin Center for Education Research and is a collaborative effort of the College of Agricultural and Life Sciences, the School of Education, the College of Engineering, and the College of Letters and Science. The collaborative effort is also joined by the National Center for Improving Science Education, Washington, DC. Any opinions, findings, or conclusions are those of the author and do not necessarily reflect the view of the supporting agencies.

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CONTEXT OF SYSTEMIC REFORM**

Christopher A. Thorn, Jeffery Watson, & Susan Zeyher

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June 2001

About the Authors

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Susan Zeyher, former NISE Fellow and Research Specialist in Library and Information Studies, served on the Information Resource Coordination Team. Her work involved assisting students and teachers of grades 6-12 to discover Web-based educational resources specific to science, mathematics, engineering, and technology. She developed a classification scheme for these education resources. Zeyher attached a controlled vocabulary of subject terms to the resources to make searching more precise than with a Web browser.

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Introduction

Norman L. Webb

An important issue that confronts the administrators of large education systems, evaluators of education systemic reform, and the monitoring of any large education system is the management and analysis of large amounts of data and information. This issue is not new and it is one that many states and districts are currently addressing. For example, one important criterion for a school district revising its information system is for data to be reportable and retrievable at all levels of the system, including that of individual students, the classroom, the school, and the district.

Over the course of five years, the NISE Systemic Reform Project has made a series of studies of systemic reform. One effort, guided by William Clune, has focused on the policy and theory of systemic reform in mathematics, science, and technology education. The second effort, which was a derivation of the work that produced this monograph, has focused on the evaluation of systemic reform. It is apparent from our efforts in studying methods and strategies for evaluating systemic reform that there is an important need to have data and information accessible to state and large district education systems that are attempting to judge their systems' continuous improvement in mathematics, science, and technology education. Many systems have data available on student outcomes, teachers' professional development, classroom practices, and financial resources. But the data environments in these systems do not have the capability for studying the relationship among variables and for readily reporting findings from these studies.

Purpose and Goals for the Project

The study of information networks (InfoNets) is a continuation of the National Institute for Science Education (NISE) Systemic Reform team's work. The purpose of this study is to produce an analytic framework that can be used to describe and project those ways in which data environments can function within education systems and support the advancement of these education systems toward systemic reform. There are a number of audiences for the InfoNet Study. The study seeks to inform those who are engaged in systemic reform, those who work in education systems, those who are thinking about and designing data tools for large education systems, and those who are interested in how data can inform education decisions. Evaluation and monitoring are important functions of education systems that seek to perform more systemically. At the same time, these education systems also are pressed to perform normal operations, including administering a large organization, certifying student learning, reporting compliance with regulations, and meeting the educational needs of the public, among other activities. Thus, although the main interest for the InfoNet Study is evaluation and monitoring, the study has to be responsive to all of these other data needs within the system.

NISE is invested in improving science, mathematics, engineering, and technology education in the United States. Because this study is being conducted under the auspices of NISE and is funded by the National Science Foundation, illustrative examples are drawn from science, mathematics, engineering, and technology education. But a viable information network for any

education system has to attend to and incorporate all of the vital needs and content areas of a comprehensive education system. Therefore, it is important that the analytic framework produced by this study is applicable for analyzing data environments within the entire system and is not limited to the support only of science, mathematics, engineering, and technology education.

This study of InfoNets was conducted in an era of rapidly advancing technology. Technological advances continue to expand the electronic capabilities for entering, processing, aggregating, analyzing, and reporting data, but system technologists confront the current archaic infrastructure of many schools, school districts, and state education systems. The analytic framework developed in this study has to consider realistically what the current capabilities of education systems are and what conditions specific applications require.

The use of data and information is not value free. Caution is warranted in taking advantage of technology's capabilities for processing large amounts of data in very short periods of time without considering thoughtfully what data are being processed, how results from the data are being used, and how such data and findings serve the best educational ends for students and society at large. In pursuing NISE's goal, it was paramount that those in the InfoNet Study not only think about information systems that can track and support student learning, but that the study also consider what science and mathematics the students are learning. Leona Schauble at a June, 1999, NISE Conference made a strong point to the effect that some data are not necessarily better than no data. She went on to clarify her comment:

If the measures in question are poor or distort what they purport to measure, they are likely to support misinformed decisions and bad policy. Given the current state of assessment of learning and teaching, I believe it may well be a disservice to facilitate using those measures to guide decisions about teaching and learning. The broader the scope of implementation, the more likely it is that such technologies would have a dampening and narrowing effect, rather than a facilitative and reforming effect on students' learning.

. . . There is currently not in place in schools a culture for using data to support continuing improvement in teaching and learning. Our study should be on how that cultural shift has been/can be achieved, not on tool development. Powerful tools dropped into misaligned cultures are liable to either be (a) ignored or (b) distorted to pre-existing norms and purposes.

The developers of an analytic framework for analyzing information networks as applied to educational needs have to consider not only producing information on student learning, but also the quality of the content that students are learning.

Overview of Papers

The papers in this monograph further the work of developing an analytic framework of InfoNets. In the first paper, Christopher Thorn draws from the literature on knowledge management to describe the general context for thinking about education information networks. His paper

highlights the importance of distinguishing among data, information, and knowledge. Whereas InfoNets attend to the information needs of education systems, the information is derived from data and used by stakeholders to increase their knowledge. On the other hand, business and industry, by necessity, are seeking productive ways to manage knowledge better within their organizations because of the greater importance given to intellectual capital. This change is fueled by the speed at which information can be distributed throughout their organizations and the capacity to store large amounts of information electronically. Thorn sets the stage for analyzing education InfoNets by applying thinking from business and industry to an educational setting. In his paper, he identifies the organizational structure of education systems and the necessary conditions for knowledge management in education systems, such as the need to focus on student learning. He discusses important issues critical in developing an analytic framework for InfoNets that provide both approaches to studying the use of information and the value that should be given to different forms of information.

A second paper by Jeffery Watson and Susan Zeyher focuses in some detail on the four major dimensions that can be used to analyze education InfoNets from a systemic perspective. User needs are critical for evaluating which information system and tools will most effectively serve an educational system. Data characteristics are important as a basis for determining how data are to be organized, aggregated, stored, and retrieved. Analytic structures define what system-based methods are available to analyze data. Technical considerations address the technical issues faced when implementing an information system and tools in an education system. Watson and Zeyher elaborate on these four dimensions, producing a paper that is both instructive in explaining components for information systems and practical in providing specific criteria for analyzing information systems for education.

Knowledge Management for Educational Information Systems: What Is the State of the Field?

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Abstract

This paper explores the application of Knowledge Management (KM) techniques to educational information systems—particularly in support of systemic reform efforts. The first section defines *knowledge* and its relationship to *information* and *data*. There is also a discussion of various goals that might be pursued by organizations using KM techniques. The second section explores some of the fundamental design elements of an educational KM system. These include questions surrounding the unit of analysis, distributed computer resources, and organizational characteristics of successful KM efforts. Section three outlines the benefits that organizations expect to gain by investing in KM. Section four is a case history of the introduction of a district-level data system and the parallel efforts to support the aggregation and reporting of high-stakes educational outcomes for 6th grade students in the Milwaukee Public Schools (MPS) district. Finally, there are some preliminary conclusions about the capacity of the MPS district technology policy to respond to the knowledge management needs of a decentralized system.

Introduction

This paper considers the critical role played by the “management of knowledge” in education, and, specifically, in efforts at educational reform. Schools and districts in the United States face mounting pressure to demonstrate the measurable effects of their practices to legislators, parents, the business world, and the public at large.¹ This fact by itself adds to the information management burden placed on the educational system. However, other changes, such as the rise in student mobility and ethnic diversity, have increased the complexity of already complex school data systems. This complexity is rooted in the operational requirements of implementing and assessing instructional interventions and the interactions between racial, ethnic, and socioeconomic characteristics on student learning. The permutations of analytically distinct groups increase knowledge management burdens at an alarming rate.

As growing diversity has been matched by increasing disparities in educational outcomes between a number of groups—poor and affluent, white and minority, urban and suburban—a patchwork of uncoordinated programs have been introduced at all education levels by a variety of government entities. This *ad hoc* form of policymaking often results in programs that at best do not reinforce one another and at worst actively work to undermine each other. For example,

¹ For an overview of the literature on standards-based reform see, for example, the National Council of Teachers of Mathematics standards website at <http://www.nctm.org/standards/> or Kirst and Bird (1997) at http://www.wcer.wisc.edu/nise/Publications/Research_Monographs/vol2.pdf

the move to base access to Title I resources on economic rather than academic need was an important shift in emphasis that allocated resources more equitably. Unfortunately, a number of local programs in many urban school districts relied on the annual testing funded by Title I as an important component in assessing overall system performance and often used the data to inform local goals. A more promising response, which has developed over the past decade, has been what is referred to as *systemic* or *standards-based reform*. Systemic reform, according to U.S. Deputy Secretary of Education Marshall Smith, is typically based on state-level reforms that implement more rigorous content and performance standards across grades and disciplines.² Systemic reform requires that curricular material and assessments be aligned with these standards. Preservice teacher education and teacher professional development must also support these goals. Finally, funding, technology, physical plant, and human resources must all be allocated in such a way that each group has equal access to the things it needs in order to succeed. To improve student achievement and to close the equity gap are the ultimate goals of systemic reform efforts, but supporters of systemic reform believe these goals can only be achieved by improving all aspects of the educational system.

Major systemic reform initiatives at the national level seek to strengthen teacher education, reinvigorate the development of high-strength curriculum, and promulgate disciplinary standards. Some of these programs operate under the auspices of the U.S. Department of Education and the National Science Foundation.³ The majority of reforms are state-level initiatives to improve the performance of students in specific subject areas or grade ranges such as elementary reading or middle school mathematics (Armstrong, 1999). Individual districts also engage in reform initiatives that seek to motivate particular schools or groups of students to meet individual standard components. Finally, individual schools and classroom teachers work to develop lesson plans to teach concepts based on grade-level standards. These trends and the consequent emergence of more data-rich environments raise the need for new technologies and new management techniques for coping with complexity. Three technical issues in particular appear to be especially crucial.

First is the problem of accurately identifying policy targets. Identifying the target group and the desired outcomes for a particular reform is necessary if one is to describe, analyze, and locate reform efforts within educational systems. Existing organizational identifiers such as school, classroom, or demographic data are often inadequate to isolate for study or evaluation students or teachers who participated in particular programs or received distinct treatments. The ability to accurately compare analytically distinct groups is vital if one is to assess the impact of systemic reform.

Second is the problem of managing data. It is evident that successful systemic reform will depend on access to and effective use of large amounts of data. This means that the quantity, timeliness, and level of detail of the data needed from decision-support systems will only increase. Proponents of systemic reform point to the importance of a process model and

² This definition is adapted from an address given by Deputy Secretary Smith at the National Institute for Science Education 1999 Forum.

³ See, for example, the NSF Educational System Reform site at <http://www.ehr.nsf.gov/EHR/ESR/index.htm> or the Department of Education's National Research and Development Centers at <http://www.ed.gov/offices/OERI/ResCtr.html>.

evaluation framework for assessing programs (Clune, 1998). The process of systemic reform must include actors from all levels and it must include an awareness of resources and barriers confronting actors across educational roles. The focus on process also points to the importance of quality indicators. Quality measures might include a detailed analysis of curriculum goals and well-understood, publicly available education standards. High quality instruction demonstrates an alignment between standards, curriculum, and assessment. The difficulty of measuring differential interventions is compounded by the need to gauge the quality and thoroughness of new, robust curricula and to obtain more detailed analyses of student progress.

Third is the problem of metrics, i.e., multiple-choice versus authentic-performance tasks. Demands for more authentic assessments have led to calls for new metrics of student performance relative to standards, as well as an emphasis on measuring a particular student's attainment of individual proficiencies.⁴ The new standards-based approaches have led to the creation of new sorts of testing that go beyond the typical "fill in the bubble" standardized assessments. The introduction of multifaceted testing regimes (including traditional standardized tests, as well as performance- and portfolio-based assessments) both increases the complexity of the individual instruments and creates new requirements for the underlying data systems that must both record and provide an analytical environment for the data. The increasing sophistication of assessment practices calls for a parallel development in the arena of information-management strategies.

The problems described above are the technical aspects of fundamental research questions—What to study? How to aggregate the data? And what are the appropriate measures? As our understanding of the educational process deepens, our technical capacity to collect, manage, and analyze data must keep pace.

This paper seeks to apply insights from the growing body of literature on knowledge management (based primarily on research coming out of United States and European business schools)⁵ to the specific case of systemic reform in U.S. education. Knowledge management (KM) strategies can serve as valuable tools for decision makers at all levels of the educational system. In this paper, I focus on outlining the distinctive features of knowledge management, identifying the characteristics of successful KM efforts and exploring the usefulness of KM for making important educational decisions. I conclude with a discussion of the role of information technology (as a component of a KM system) in the implementation of high-stakes accountability for 8th grade students in one particular urban district, that of Milwaukee, Wisconsin.

Knowledge Management (KM): Definitions and Scope

Before considering the characteristics of knowledge management, it is important to note the differences between *data*, *information*, and *knowledge*. A recent article by Laura Empson, which

⁴ For more on authentic assessment, see Neumann, Secada, & Wehlage (1995).

⁵ For some of the best examples of this literature see the Journal of Knowledge Management at <http://www.mcb.co.uk/jkm.htm> and resources links at the Financial Times *Mastering* series web site at <http://www.ftmastering.com/links.html>

presents the argument that knowledge is a product that is built from data and information, provides the following definitions:

[I]t is perhaps easiest to understand knowledge in terms of what it is not. It is not data and it is not information. Data are objective facts, presented without any judgment or context. Data becomes information when it is categorised, analysed, summarized, and placed in context.

Information therefore is data endowed with relevance and purpose. Information develops into knowledge when it is used to make comparisons, assess consequences, establish connections, and engage in a dialogue. Knowledge can, therefore, be seen as information that comes laden with experience, judgment, intuition, and values. (Empson, 1999)

There is a clear progression along the path in which value is added to data, as context is combined with it to create information. A further transformation occurs when human experience is added to information to make value judgments about, and comparisons of, different information.

The progression from data to knowledge can be seen both as a temporal process in which data, imported into a system's architecture, aggregates individual facts into summaries and averages that are then presented in an appropriate context. In an educational setting, this might be a report of student test performance by grade, ethnicity, race, and gender. The addition of deeper contextual information about local school leadership, particular organizational characteristics, or other less quantifiable factors can be combined with mechanistically generated test-score results to describe variance in outcomes that could not be extracted from the more traditional reports. It is this application of personal knowledge and of well-designed models that differentiates information systems from knowledge systems.

Knowledge Management as the Use of Data and Information

As mentioned above, KM is a follow-up to information management. The bulk of the literature on good information system design focuses on the technologies and processes used to *acquire and manage* data. When describing the breadth of approaches to effective knowledge *use*, a number of authors describe a range of system functions from data management to knowledge creation and application. Information management lies somewhere between the two poles of data management and knowledge management. Another way to think about KM is that it is the use or application of information.

In districts, the student data system provides the core of such a system. However, this focus on information systems and tools for aggregation and on KM as the application of information should not imply some type of computer-based system that is somehow imbued with deep contextual knowledge of the organization. This is not just a question of the technologies employed. An important role is played by institutional culture. For example, a district with a collaborative model of interaction between schools will typically display a far greater capacity to develop robust analyses of school-level processes and needs than a district lacking such a model. Davenport has identified several important questions that may be helpful in efforts to clarify an organization's approach to the use of knowledge management:

Does an organization's culture reward decisions and actions according to how people use and share their knowledge? Or is it content with the widespread use of intuition and guesswork at the expense of organizing people and processes to apply the best knowledge, experience, and skills to projects and tasks? (Davenport & Davenport, 1999)

The Davenports point to the importance of organizational culture in enabling or blocking the use of knowledge. Cultures that support knowledge accumulation and application will be the most effective, efficient organizations. Organizational structures and processes provide a window into the value a knowledge management system will return to any implementer. A willingness to engage in problem-solving processes and share information with "outsiders" is an important resource for enabling knowledge management efforts.

The Objectives of Knowledge Management

One of the important questions that an organization evaluating its effectiveness needs to answer is, What is the goal of this organization's knowledge management strategy? Davenport and his colleagues conducted a study of 31 KM projects across 24 companies. The authors identified four broad types of objectives with different subtypes:

1. Create knowledge repositories – a) external knowledge (competitive intelligence, market data, surveys, etc.), b) structured internal knowledge (reports, marketing materials, techniques and methods), and c) informal internal knowledge (discussion databases of 'know how' or 'lessons learned').

In an educational setting, curriculum aids might be thought of as knowledge repositories. For example, the Milwaukee Public Schools Curriculum Design Assistant⁶ (CDA) is both a source of documentation—standards, learning goals, etc.—and a repository for instructional plans based on this documentation. These lesson plans can be stored in the system and shared with others electronically to provide a knowledge base for a wider audience.

2. Improve knowledge access through a) technical expert referral, b) expert networks used for staffing based on individual competencies, and c) turn-key video conferencing to foster easy access to [geographically]distributed experts.

Examples of this sort in public school education are probably rare, but the Community of Science online database⁷ is a data and communication resource that functions well in education research: it links researchers, research intuitions, and funders together. The purpose of the Community of Science online database is to reduce the barriers for those seeking funding for research, as well as to reduce the difficulty of funders in locating qualified researchers.

3. Enhance the knowledge environment – a) change organizational norms and values related to knowledge in order to encourage knowledge use and knowledge sharing, b) customers may be asked to rate their provider's expertise.

This objective focuses on the creation of a technological environment that will contribute to the social transformation of an organization. Anderson Consulting used this sort of approach to

⁶ http://mpscda.milwaukee.k12.wi.us/html_files/Purpose_cda.html

⁷ <http://www.cos.com/>

radically shift norms of information sharing and use among its consulting staff (Graham, Osgood, & Karren, 1998; Greengard, 1998). In the consulting business, there are traditionally strong norms about keeping personal expertise personal—it represents a large portion of individual competitive advantage. Anderson Consulting wanted to reverse this behavior and reward those who shared information with other consultants within the organization. The company began to make participation in an online, e-mail-based, problem-solving environment mandatory. Eventually the bar was raised further and pay and promotion were linked to the number, quality, and immediacy of an individual’s responses. This approach was draconian, but it was successful in building both a compelling repository of problem-solving information and shifting or overturning a strong norm against sharing information. This approach models an important tool for accumulating and diffusing successful educational practices. The call for methods of replicating successful programs and school initiatives that “beat the odds” could be addressed with a system that improves communication within educational systems.

4. *Manage knowledge as an asset* – a) attempt to measure the contribution of knowledge to bottom line success. (Davenport, DeLong, & Beers, 1998, pp. 45-48)

While this final KM objective sounds the most compelling, it is also the most difficult to operationalize. Even firms with excellent data-management practices and sophisticated conceptions of return on investment have difficulty assessing the return on intangibles. Learning Landscape⁸ is an example of one such effort in education. This system was an outgrowth of the Connecticut Academy’s NSF-sponsored Statewide Systemic Initiative. The Connecticut Academy worked together with the consulting firm, KPMG, to develop a data warehouse environment based on the National Center for Education Statistics’ core data elements. The stated purpose of the project was to *transform data into knowledge to improve student achievement and teacher quality*. This project was abandoned after it became clear that the development costs would exceed what most districts would be able to afford. A new firm has been established, EdExplore, which has the same KM goals but is much more limited in scope and has implementation costs in line with district resources. EdExplore remains focused on bringing cutting-edge approaches to data warehousing to the evaluation of student and teacher performance.⁹

These different goals are not mutually exclusive. Davenport states that most projects his team studied were focused on one of these goals, but many had features of the other goals interwoven into their projects (Davenport, De Long, & Beers, 1998; Davenport & Prusak, 1998). In addition, the first three objectives can be seen as constituting a feedback loop. Repositories must be built. Then, these repositories are only useful if users have efficient access to the knowledge contained in them. Finally, the use of knowledge in an organization will be enhanced by the creation of an environment that supports this use. This *knowledge-friendly* environment will, in turn, demand higher levels of sophistication in the knowledge repository, thus closing the loop.

The fourth goal—determining the return on investment in knowledge management—is closely related to efforts that attempt to determine the return on investment from spending on early research and development. Many analysts have struggled with this vexing issue, which remains

⁸ <http://www.eims.org/>

⁹ streifer@eorls.com

only partly addressed. There are so many unquantifiable, human elements in a KM system that it may be very difficult to come up with metrics that are generalizable.

Knowledge Networks and Educational Systems

There are several problems that must be faced by any educational system that attempts to create a knowledge management system. The first problem is to determine the appropriate level of analysis the system is designed to support. Another is that of differential access to computing power and the technical and analytical skills of the knowledge consumers within the system. In an educational setting, users representing students, classroom teachers, principals, and district administration should be involved in the design of a system destined to support important instructional and policy-level decision making. It is only by including users at all levels of the knowledge system that designers will have the input necessary to grapple with the problems identified above.

The arguments of the authors cited thus far in support of knowledge management systems provide very little insight into the exact analytical approaches one would use in any particular scenario, since so much depends on the organizational form, sector, or level of analysis. The discussions in the literature focus instead on families of tools designed for pattern detection and predictive modeling. It is important to bring these together with the experience of those working in the specific domain to identify the important dimensions of knowledge in that field, since we have defined knowledge as the application of information in context.

A crucial feature of educational systems is that they are made up of a number of nested systems or organizations. In analytical terms, this can also be described as *levels* or *units of analysis*. In education, these levels range from the federal level, through the state, district, school, classroom, and student levels. Reporting and analytical needs differ from level to level as do the relevant time scales. For example, there are classroom needs for lesson planning and local testing. At the school level, Title 1, free lunch, state-mandated testing, and other mandated programs are focal points of data-management issues. The reporting requirements are as numerous as the funding sources at each level of the organization. Analytical needs differ, but are present at every level of the system. A robust knowledge management system must reflect the information and knowledge management needs of all levels. In particular, data must be gathered at a level of aggregation appropriate to the user with the most fine-grained analytical needs.

The Level-of-Analysis Problem

The most common focus of school information systems is on the school- and district-level reports produced by a central information technology department. In the case of school district-level knowledge management systems, one might attempt to implement several KM systems as described above by Davenport. One could argue that schools are groups of professionals with both process and content knowledge. One organizational model used to describe reform-based schools—“communities of practice”—would suggest that they would be more likely to focus on enhancing a knowledge environment (Snyder, 2000; Wenger, 1998). Operating under this model, schools would be less likely to accumulate knowledge for its own sake. They would focus, instead, on sharing knowledge among a group of professionals. This would be consistent with the

view that schools are communities of learners. A KM system that supports such behavior would be both a repository of successful practices and a system for conveying positive norms associated with sharing knowledge.

The importance of the level of analysis comes to the forefront of any effort to describe and apply KM principles. For example, district-level functions might include analysis of the quality of the data in the system (this may be in formal terms of validity and/or reliability, as well as of alignment of the metrics in use and the learning or performance standards). District-level analysis might also focus on the curricula that are in use across the district and assess their relative effectiveness. These district-level functions call for nested hierarchies of approaches to systems design that support collection of the relevant data and aggregation of these data to the appropriate level of analysis.

The identification of distinct levels in an organization with different KM needs is even more vital if one considers the increasing demands technology places on individual units in an organization. Boisot argues that the traditional neoclassical economics concept of a linear relationship among the different factors of production fails to adequately explain the returns of knowledge (Boisot, 1998). Boisot points out that as one moves up within an organization, the number of elements that must be integrated in order to produce a good or service has probably not increased dramatically in recent years. However, the pace at which new technologies and needs are introduced and old technologies become obsolete has increased dramatically (Boisot, 1998). This rapid pace of change in the factors of production places a premium on the ability of individuals within an organization to track change and respond to it. This ability is one of the key features of successful KM.

Unfortunately, this is an area in which traditional information management systems (such as SASIxp™ or ABACUSxp™ from NCS or eScholar from IBM and Vision Associates) are particularly weak in general.¹⁰ Data warehouse systems are excellent tools for making complex selections of data from many different sources. However, there are no good inferential or predictive models in place within commercial school decision support systems for modeling school or student behavior in real time. This is not because there is not a rich understanding of student achievement. Rather, the cost and complexity of real-time KM systems represent a major obstacle to schools or districts taking advantage of this technology. Schools have lagged behind industry in replacing paper-based clerical and business functions (often referred to as back office functions) with technology-based systems. They often lack the physical infrastructure necessary for communication between numerous geographically dispersed buildings.

Increasing Access to Computing Power

The rise of *ubiquitous computing*, which places relatively inexpensive devices for information storage and manipulation on every desk, has made the conversion to technology-based systems possible. This trend is now finding its way into schools as they move away from using computers for rote learning to employ them as information tools. This is not simply a centralization-

¹⁰ Information about NCS can be found at <http://www.ncs.com/>. IBM's school and district management site can be found at http://houns54.clearlake.ibm.com/solutions/education/edupub.nsf/detailcontacts/edu_schools. For more information about eScholar go to <http://www.escholar.com>.

decentralization issue—i.e., the spread of technology from the district to the school and classroom. These resources can serve additional goals outside of instruction. A personal computer is both an information-gathering and an information-manipulation tool. The availability of computing at all levels of the educational system can be a focal point of change.

There are certainly budget, security, and management implications in broadening access to sophisticated computing technologies. However, the need for information transcends district governance issues. Moves toward greater local autonomy and responsibility—whether in response to school vouchers, charter initiatives, or other pressures—mean that there will be an increasing need for local analytical capacity. The need for well-informed local decision-making at the classroom level is not unique to any particular organizational form, however, such as block scheduling, or multi-age classrooms. It exists in both flat and hierarchical organizations.

The level at which decisions are made may differ across organization types, but there must still be robust data-collection and knowledge-dissemination mechanisms at all levels. This is particularly important given the different uses of individual data elements at different levels of aggregation and at different levels of the organization. Even at the school level, one can demonstrate the utility of comparing groups such as students who are bussed versus not bussed, or students participating in a specific after-school program versus students who do not. Traditional aggregations of data in such instances prove inadequate.

Student Data as the Basic Unit of Analysis

The problems outlined above suggest several possible avenues of system design that would lead to more appropriate data structures and produce more useful knowledge in an education knowledge management setting. The focus on student learning, and the persistent gaps in student achievement described above, should suggest to system designers that knowledge management systems should be student focused. What this means is that individual student data must comprise the basic building block of any knowledge management system in education. This includes data about the students themselves (test scores, demographics, attendance, etc.), as well as data about *treatments* or interventions intended to influence student outcomes. So, for example, professional development efforts aimed at improving the teaching of reading comprehension would need to be tracked, since these should have an impact on student learning. This implies that the school or instructor should collect the data locally and that the data should be used locally to inform teaching and targeted intervention programs. This is an important point that is often overlooked. The most basic common unit of analysis (sometimes referred to as an *atomistic* unit) should drive data-collection efforts and processes. If the student is the smallest analytical entity that will be studied, then attributes of that entity should be collected. In schools, this means that data should be gathered at the source. If schools and classrooms are where learning is produced, then local teachers and administrators need to collect and understand the data that will be used to measure that learning.

At the same time, however, districts need to integrate increasing demands for accountability, both fiscal and educational. Increasing scrutiny at the district level implies an entirely different focus for information system design. In this district accountability model, data are aggregated up to higher levels, such as the school or program, and are used to justify administrative or

managerial decisions that affect large numbers of students and schools. This does not simply mean a reliance on central capacity. Knowledge management should be responsive to needs at all levels of the system. The problem is that the events and outcomes being monitored all tend to occur at the lowest levels of aggregation—the student.

Even in the most centralized system, instructional outcomes occur at the individual level. However, most district accountability measures and goals are aggregated to higher levels of the organization. Data on student and teacher absence, student program participation, teacher professional development activities and test scores need to be available at the lowest level for aggregation to any meaningful unit—classroom, grade, neighborhood, or other coherent grouping. This means that only individual-level data will serve. This is important because reform efforts must work on multiple levels. It is also vital that the system be transparent in order to combat efforts to cheat or otherwise tamper with the data. Data collected at the student or classroom level need to be aggregated and fed upwards to higher levels of the educational accountability structure to inform system decisions made at those levels. A system without proper security in place could be subject to manipulation by school-level actors. Again, this is not an argument for or against centralization, *per se*. Rather, one must recognize that there are knowledge management decisions that are appropriate and possible at each level of an organization. Data structures and analytical tools should reflect this reality.

This divergence between existing data systems and data needs points to a gap between new technological capabilities and the policy environment that would enable schools to actively collect relevant information and put it to use in a KM system. When the model of change targets student learning, it is essential to focus on identifying those innovations (technical and organizational) that best serve schools and classroom teachers. Most existing models of school governance do not provide for data analysis at the classroom level. Often there is also a gap between technical capacity and technical feasibility. Most educational systems have very little technical capacity. For example, teachers may not have easy access to the Internet, or district computer staff may not have much experience supporting the analysis of problems relevant at the classroom level. There must be collection and delivery systems in place. There must also be analytical support for complex problems that are not solved by looking at simple bivariate comparisons. What technological capacity does a school system need? That depends on the system's goals.

Making instructional decisions in an individual classroom requires a sophisticated understanding of student attributes and of what individual curricular units can provide. The ability to generalize to a larger population is not a relevant concern in this context. At the school level, however, a principal may be very interested in how a new professional development activity is affecting student performance relative to other classes in the same building, or in comparison to other schools across the district that did or did not participate in the same training. The tools and data needed for within-classroom analysis are quite different from those necessary for a cross-school comparison. Differing forms of organizational analysis call for diverse forms of KM system implementation. One faces similar challenges at any level of aggregation, from the classroom through the district level to the federal level.

This discussion does not directly address the existence or quality of data needed for analysis. The lack of reliable data for school and student evaluation continues to be a vexing problem. Without a solid analytical model and the appropriate KM infrastructure to collect and aggregate the data, no district of any size would be able to implement a robust evaluation system. For example, many districts embrace an assessment policy that focuses on individual grade cohorts. This has led to the construction of information systems and testing plans that do not support longitudinal analysis of individual students. However, a system that allowed for accurate and fair evaluation at all levels of the educational system would differ radically from the current model that separates data use and evaluation (occurring at the state and district level) from the people who actually do the teaching and learning (schools, teachers, and students). A fair, consistent knowledge management system would provide an environment for implementing an *appropriate* stakes model at each level, rather than focusing *high-stakes* measures on teachers and children.

Variations in Organizational Approaches to Knowledge Management

Differing organizational approaches to knowledge management are one of the most broadly discussed areas in the field. Much of the recent literature that seems to be relevant for KM is based on the study of complex commercial organizations—primarily large, multinational, financial, and high technology firms—and comes out of the major business schools in the United States and Europe. These studies of KM point to a number of issues that educational technologists must address in the design of school district information networks before we can make significant progress in areas that range from measuring individual student performance to the most demanding evaluations of large districts and state-level educational systems. The contributions of research on knowledge management to school and district can be applied most directly to strategic planning efforts. The work of Marchand (1999), Feeny and Feeny (1999), the Schools Interoperability Framework¹¹, and the National Center for Education Statistics all provide assistance in applying KM principles to planning and evaluation.

Donald Marchand argues that organizational reform efforts can often best be described by the way in which they operationalize their KM strategies. He describes four important dimensions of such strategies, as shown in Figure 1 (Marchand, 1999). On the horizontal axis, managing costs and risks are straightforward concepts. On the vertical axis, adding value implies increasing ones return on investment. New realities can be conceived of as both creating new services or goods and creating relationships with new customers. Points near the center of Figure 1 represent little or no activity along an axis, while points farthest from the center represent best practice.

In this example, Organization A is an organization that sees innovation in information technology as a way to reduce risks and costs. A school district following this strategy might implement a new in-school, computer-adaptive mathematics assessment to reduce outside testing costs and to help minimize instructional time lost to testing. Such a system might also help address the problem of mobile students who may not be included in once-a-year standard assessments. Such an assessment would be an element of a comprehensive program to reduce the risk of litigation associated with differential outcomes between poor and non-poor students by providing the opportunity to test adaptively and at smaller time intervals.

¹¹ The SIF site can be found at <http://www.schoolsinterop.org/spec/Acknowledgements.htm>

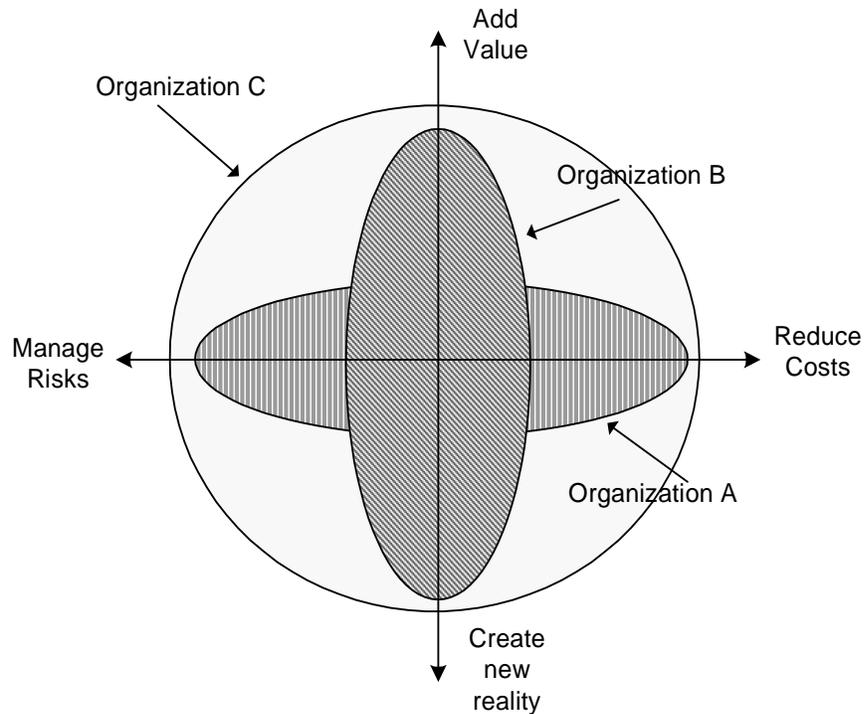


Figure 1. A graphic that illustrates how information creates business value (Marchand, 1999).

Organization B, on the other hand, perceives the value of improvements in information management as coming from adding value or enhancing existing interactions and creating new information services and products. A school following this strategy might invest in workgroup computers and a high-speed Internet connection. This technology would be used to support teaching a chemistry class in a virtual, web-based environment that would allow for the interaction of commercial and university subject-area experts as outside advisors and mentors for student projects.

Marchand argues that an effective organization with a well-designed information management plan will have a clear understanding of its place on these dimensions and will plan for its development needs accordingly. It seems clear that an organization with a mature understanding of the importance of information for decision-making might map its strategy onto Marchand's graphic as a circular structure, Organization C. However, the costs involved in moving a complex organization along multiple axes simultaneously would almost certainly be prohibitive. It is important to recognize the tradeoffs between adding to and protecting what already exists. A balanced strategy would reflect this.

Mapping one's own organization on this framework can provide some important insights. No single effort can conceivably score high in all four dimensions, but a comprehensive knowledge management strategy ensures that, as a whole, investment in appropriate technological innovation addresses all of an organization's major goals.

Marchand discusses another dimension not explicitly captured in this graphic. Is a particular knowledge investment required for operation, is it essential for competition, or is it likely to bring distinction as a unique actor in the relevant market? Most investment in operational data systems tends to be directed toward the first two areas, day-to-day function and competition. It is the concept of standing out from the crowd that helps to drive truly innovative transformations of KM systems. In his research, Marchand finds that managers “rarely say that significant portions of their investments are focused on applications that give them distinctive competencies with customers” (Marchand, 1999). The immediacy and relative clarity of an organization’s current operational needs tend to drive most KM investment strategies. This is no less true for school districts. Any district will have a working payroll or bookkeeping system. There is no other alternative. These systems must be operational and deliver substantial value. Investments in long-term payoffs, such as those often encountered in improving educational systems, typically suffer by comparison. A system for tracking curriculum development and delivery is typically not characterized by a sense of urgency. The rationale for building such a system is less clear-cut than for the other, more traditional, operational data systems. Operational systems track and manage day-to-day transactions but are of little use for planning or evaluation purposes. However, as is the case with basic research in the manufacturing sectors, there needs to be substantial investment in a knowledge management infrastructure for any organization to reap long-term payoffs. The return on investment from knowledge is small in the short term but can have a huge impact in the long run.

If one applies Marchand’s dimensional framework to schools and asks how information creates value in an educational setting, the level of analysis becomes extremely important. For example, one focus of a school district, because it performs the business functions of any large organization system, would be on managing risks and reducing costs. District administrators would also be interested in producing increased learning, but they could only have an impact through indirect effects. One model of district action would be an active structuring of incentives and resources to create an environment in schools and classrooms that enhances learning. Bureaucratic structures are good at routine tasks and can provide infrastructure at a reasonable cost by taking advantage of economies of scale. Individual teachers, on the other hand, are engaged in directly adding value to the educational process and creating new realities for their students. This is a case of functional specialization. The problem is that actors at each of the levels need to be cognizant of the knowledge and system dynamics that define the other levels.

Even within a district office, there will be differences across organizational boundaries. Curriculum support staff might be heavily focused on "creating new realities" by aligning district curricular resources with new standards or goals. This might include a “training on demand” streamed video system for delivering professional development when and where it suits individual teachers and coordinators. Using technology to overcome the boundaries of time and space can create many new opportunities. A legal services team might be focused on reducing risk: for example, a district might put all Individualized Educational Plans (IEPs) online with a system for tracking interventions and student performance. This might be one response to concerns that special education students are receiving uneven access to services. This system could provide both a tool for demonstrating compliance and encouraging school staff to stay on top of student needs by making school-level activities more transparent. This drastic over-

simplification highlights the difficulties one encounters when trying to design a system that meets the needs of actors at multiple levels in the educational setting.

It should be made clear that it is not necessary to build one monolithic knowledge management system. Indeed, it would be extremely difficult to build a complex system that would be adaptable enough to respond consistently to a changing educational policy environment. A resource that has been developed in this regard is the Schools Interoperability Framework, which is an important acknowledgement of the heterogeneity of data-acquisition and knowledge-management systems in use today.¹² Any realistic district information system must be made up of a matrix of interlocking systems that serve different functions and different user communities.

Risk versus Investment in Information Technologies

School districts are not unique in their spotty reliance on information technologies designed to enable and monitor reform efforts. Many district-level systems were created to comply with externally imposed reporting requirements. Unfortunately, investment in *transformative* types of information technology—technologies that will impact the underlying organizational goals and drastically expand capabilities—is inherently risky. In a recent study of large information technology projects, David and Leslie Willcocks Feeny found that over 70 percent of these projects went over budget and missed their completion deadlines. They note that

. . . the risks are even greater when, as with many Internet applications, real business innovations are also being looked for. The main reasons for disappointment cited also remain stubbornly familiar: incomplete definition of business requirements, insufficiently detailed technical specifications, changing business requirements, and lack of business user input during development. (Feeny & Feeny, 1999)

Innovation in knowledge management is difficult in a complex organization. In education, we have long experience with the problem of differentiating direct and secondary effects. The expectation is that improvements in the educational setting—investments in class size reduction, teacher training, access to computers, etc.—will translate into improved learning on the part of the students. Schools and districts often engage in professional development efforts with the intent of improving student performance—an indirect effect of improving instruction. However, studies of the effectiveness of such efforts are often hampered by the difficulty of isolating and measuring the value added by a particular professional development program to performance at the individual student level (Kennedy, 1999). Expectations that simple technology initiatives will adequately address such complex problems are wildly optimistic, at best.

Unrealistic expectations are as likely to be attached to smaller-scale applications of technology as they are to large technology systems. One smaller-scale technological “fix” that is frequently advocated is the availability of computers in classrooms. Proponents argue that computers are valuable tools and resources for both teachers and districts. However, what frequently goes unrecognized is that, in order to live up to the expectations and serve the needs of both teachers and district administrators, computers must become an integral part of the classroom

¹² For a list of organizations involved in developing an interoperability framework between school and district information systems see, <http://www.schoolsinterop.org/spec/Acknowledgements.htm>

environment. Technology used as just one more *add-on* activity will have very little educational impact other than perhaps increasing keyboarding skills. There must also be sufficient computing resources in the classroom with links to district-level data systems that allow individual teachers to make meaningful queries in real time. If one believes that frequent measurement is critical for gauging the value added by a particular educational strategy, the ability to record and evaluate data in real time is crucial. District or state level analysis, on the other hand, would be a centralized, top-down approach that would have little use for complex data structures and would only rely on school-level technology for acquiring data. This distinction in interest between consumers of data at the different organizational levels also reflects the need for a more global understanding of the importance of the timeliness of data collection and rapid turn-around for results that are to aid decision making at the classroom level. The tension between district and classroom needs remains a troublesome barrier with respect to both turn-around time and the expected payoff for the time invested. Districts need data that are not immediately useful in the classroom (but must be collected there) and classroom teachers routinely assess their students and vary their interventions based on those assessments.

Finally, there is a serious question about the validity of the measures of student learning used at both the school and district level. Teachers often question the alignment of standardized tests with enacted curricula. There are also concerns about the consequential validity of using such tests to make high-stakes decisions about the progress of students and the retention or pay of teachers. By the same token, while a classroom assessment may be valid within that classroom, the reliability of such measures is too low to be useful for comparing student progress within a school or across a district. This is a problem that technological innovations can address, but not in purely technical terms. The design of new assessment instruments may be enabled by new delivery and recording technologies. The rapid growth of computer-adaptive testing and its immediate scoring and reporting of results represent an enormous change from the typical “fill in the bubble” examinations. Wide access to digital video has made the production of multimedia portfolios of student work a reality in many non-affluent schools. This is an area where the landscape is changing rapidly. As distance technologies improve to allow teachers to collaborate with subject-area experts, master teachers, test constructors, and others, it will become easier to work together on test quality and comparability. The social organization of classroom support structures will need to change as well, but the hope for coordination at a higher conceptual level can be realized.

Expected Benefits from Technological Innovations

There has been a great deal written about new forms of technical infrastructure and about the role that enabling technologies play in knowledge management. Schools often have very little in the way of technological infrastructure on site. However, the current thinking about successful knowledge management warns against relying on technology to solve the whole data management problem.¹³ Dorothy Leonard-Barton (1995) suggests that the importance of “core technological capabilities” is a myth developed by managers looking for stability in rapidly changing environments. Instead, she provides a list of *non-technological* characteristics of what she refers to as renewing (or successful) organizations, summarized as:

¹³ Others have written more extensively on the computer-human interface. Two examples of this work are Rouse, 1991; Shneiderman, 1998).

Enthusiasm for knowledge - Knowledge seeking and accumulation are encouraged and rewarded. A spirit of inquiry drives people. Curiosity is seen as an important asset.

Staying ahead in knowledge - Having the drive to continue to learn and expand capabilities. Anticipating customer needs is the focus—not responding to them.

Tight coupling of complementary skill sets - Tear down internal boundaries and operate in teams. There need to be boundary spanners in each area to make these external connections—don't make everyone a generalist.

Iteration in activities - you never achieve perfection. Iterative improvements are the only constant. Developing core capabilities is more like gardening than building something—things need constant care and need to be turned under and replanted from time to time.

Higher order learning - Don't just learn from operational needs. Listening too hard to current customers (problems, etc.) can blind one to the needs of potential customers in new markets. "For every activity," the manager asks, "what is the potential knowledge-building import of this action? Is it part of a larger pattern to which I should be devoting attention? If not, should it be? If it should not be, why am I doing it?"

Leaders who listen and learn - Leaders at all levels need to be knowledgeable about the organization's technologies. Eager learners are the most effective managers. (Leonard-Barton, 1995, pp. 261-266)

The model of information networks explored by Leonard-Barton has implications for many types of organizational culture. The points outlined above are entirely familiar to educators: Communities of learners can be described in this way. It is not surprising that the characteristics of successful teachers and teaching are similar to those necessary for success in other areas of professional interaction. However, it is essential that the importance of the level-of-analysis problem in this area be recognized as well. Information networks that link the different levels of educational innovation will encounter greater challenges to building interest and enthusiasm for knowledge if that knowledge is of little use at a particular level in the organization—especially if it is the level that must shoulder the greatest burden for data collection (i.e., the classroom). Likewise, there are difficulties in agreeing on data structures and analytical models when purposes differ. Questions focused on the performance of a particular third-grade reading program across a range of cohorts passing through that grade will engender datasets that are quite different from those created to answer questions about the long-term impact of that same program on a single cohort of students as they advance into higher grades. The data structures, analytical frameworks, and technological infrastructure necessary to answer questions in one area or level may have little relevance in another area or level.

Leonard-Barton discussed the importance of organizational culture for supporting knowledge management activities. It is also important to consider the involvement of critical users in the creations of a KM system. David and Leslie Willcocks Feeny (Feeny & Feeny, 1999) approach the imperatives for successful implementation of information technology-based innovation from a different direction. They argue that *users* of a technology must be the focus of any development or change effort, not its target. For example, a centralized reporting system for student attendance might provide detailed output that is designed by a district staffer to satisfy a

state reporting requirement. Local schools, however, might have multiple additional needs that are not served by such a report. This is often the case when technology is developed by a central bureaucracy to serve its own KM needs. A KM system for student assessment will look very different if a district office designs it for its own use from the way it would look if it had been designed by groups of classroom teachers to support instruction.

The Feenys also point out that needs and requirements are not static in a rapidly changing complex system. Traditional approaches to system development are too linear to adequately address the dynamic, multidimensional nature of successful knowledge management systems. Another important characteristic of successful KM projects is the presence of high-level non-information technology supporters (e.g., managers not in the technology or computer departments). Since the adoption of KM technology is largely a social process, it is vital that senior operational managers support the project and show that they value active participation. These caveats seem to be particularly important for projects that attempt to integrate the needs of multiple levels within an organization. High-level support that focuses on an overriding need—such as improving student test scores—can be very effective in overcoming traditional barriers to cooperation that are often encountered in bureaucratic organizations. Needs that can be defined more broadly—that appeal to organization-wide norms or goals—are best articulated from upper levels of management and have the best chance of being widely accepted if they are sponsored by someone with no parochial interest in one system or another.

Others have addressed the problem of integrating human and technical systems. Karl Eric Sveiby has referred to information technology as the primary *hygiene factor* in KM: “IT is for KM like a bathroom is for a house buyer . . . essential because without it the house is not even considered by buyers. But the bathroom is generally not the vital differentiating factor for the buyer” (O’Dell, Grayson, & Essaides, 1998). Technology is important for efficient transfer of vital knowledge, but delivers its benefits only as it supports human communication and knowledge construction.

O’Dell and her colleagues also provide important insights about some general rules-of-thumb for KM systems. They argue that “the more valuable the knowledge, the less sophisticated the technology that supports it” (O’Dell et al., 1998). For example, large data warehouses and data mining tools typically yield low-value knowledge, while a low-tech help desk delivers high-value knowledge. This is the difference between looking at pages of tabular data on the one hand and statistical analysis and advice from an expert on the other. The expert brings personal experience, context sensitivity, and technical skill and combines it with the data at hand to produce integrated knowledge as an output. The important point of this example is that the expert interprets information—data that has been systematized. It is the aggregation of information and expertise that produces knowledge.

O’Dell, Grayson, and Essaides also suggest that the low-tech/high-tech split reflects the fact that “tacit knowledge is best shared through people; explicit knowledge can be shared through machines. Or, the more tacit the knowledge, the less high-tech the solution” (O’Dell et al., 1998). District-level information systems often contain a great deal of explicit knowledge about students and schools. Tacit knowledge is that uncodified knowledge that is based on personal experience, absorption of organizational norms, and other factors. Explicit knowledge is information that has

been written down or recorded in an information system. This might seem like a simplistic distinction, but it has important implications for decision-making and the reform process. This does not mean that the accumulation and transmission of tacit knowledge is not possible. Rather, it means that knowledge management systems must have imbedded in them some portion of the critical tacit knowledge needed to interpret information in the system at hand.

For instructional decisions, teachers and school-level administrators, for example, often operate on the basis of tacit knowledge about an individual student or group of students. These data are much more difficult to aggregate and transfer. The primary problem is not technical. Rather, it is the difficulty of developing relevant metrics for a wealth of anecdotal data. Another important example of the importance of tacit knowledge is the practice of using individuals as the focal point of reform efforts. School districts often use successful principals and other administrators as agents of change. Administrators that have been able to “turn a school around” are seen as a valuable commodity. The literature on KM refers to this process as one of using mobile intellectual capital to bring expert skill to bear on a particular local problem (Albert & Bradley, 1997). The value of intellectual capital is often the tacit knowledge about how one manages curricular changes or fosters a positive school climate. This process of conveying tacit knowledge about such a complex task is one example of a knowledge system.

The drawback is that tacit data is not easily transferred and successes at one location are not easily replicable to another. Some KM system-designers attempt to imbed the interpretation of experts in the outputs of the system; for example, one might present a bar graph of mean scores on a particular set of assessments. A more knowledge-rich presentation might include a representation of error bands around the mean, or provide a comparison to scores of the same students in a prior assessment. It is not merely that the information presented should be contextualized. It is important that the contextualization be done in a way that makes a valid comparison and enhances the explanatory power of the measure in question.

As the Feenys, Davenport, and others suggest, there are distinctions along the continuum from data to knowledge. What these authors do not provide is a detailed understanding of how one applies this continuum to an educational setting. In order to bring about the senior management participation that Feeny refers to above, it is necessary to establish the payoff of the investment in knowledge management at every level of analysis. If the unit of analysis is the student, then the other questions are derived from that. The analytical framework should focus on the individual. The data structures in this case must be available at the individual level and be sufficiently broad for meaningful diagnostic use. Making the linkages clear between different levels of the organization and building methods of capturing and using tacit knowledge are two characteristics that must remain in the forefront of any design effort.

Efforts to Reform School Data-Management Practices

Much of the work that went into this paper was informed by nearly eight years of experience working with education assessment and program data from the Milwaukee Public Schools (MPS). It has become increasingly clear that the ability of MPS to perform timely, in-depth, and accurate analysis is severely hampered by data-access problems. Indeed, there are increasing concerns that the district does not have the data it needs to make many important decisions or, if

the data exists, they resides in a computer system that is difficult to use. In our work with MPS, we hope to take advantage of two major ongoing efforts. The first is the Schools Interoperability Framework (SIF). The SIF “is an industry initiative to develop an open specification for ensuring that K-12 instructional and administrative software applications work together more effectively.”¹⁴ The initial area of collaboration will be in the area of intra-application communication. The model the SIF group is supporting is an *open-system environment*. This approach recognizes that schools and districts will continue to use a mix of information technologies from various vendors. The SIF initiative is focused on setting data exchange standards that will let the major school management and instructional support packages talk to each other without human mediation. This will help to decrease the transaction costs of systems with broader functionality and should allow for better aggregation of data across schools, districts, and states.

The founders of the SIF emphasize the need for comprehensive, consistent data management from a market-driven point of view. They argue that it is impossible to provide sophisticated applications if each individual school district pursues its own data-management strategy.¹⁵ The challenge the SIF has set for itself is based on the efforts of the business information technology community to move from data-management to knowledge-management systems. While the issues involved in successful knowledge management are largely absent in the literature on educational administration and assessment, an important and growing body of work is emerging from business schools around the world. These works range from thinking about the role of experts in organizational learning (Albert & Bradley, 1997) to multi-dimensional representations of the lifecycle of knowledge (Boisot, 1998). The *Financial Times* recently ran a three-month series reviewing the current thinking in academia about knowledge-management systems.¹⁶ This series does an excellent job of making very complex models of organizational development and impact assessment accessible to a broad audience and has helped to inform our discussions with decision makers in Milwaukee.

The second important strand of work comes from the National Center for Education Statistics (NCES, 2000).¹⁷ This effort produced a comprehensive, standards-based model for school data system definitions. Unlike a product created by a particular vendor, district-level, state-level, and federal education administrators developed this model. Rather than being market-driven, the NCES Forum on Educational Statistics focused on the decision-making needs of school- and district-level administrators. This focus on users of data turns the traditional approach on its head. Most major school software systems—such as the offerings for National Computer Systems (NCS)—are driven by a lowest-common-denominator approach, where the package provides for the minimum needs for the maximum number of possible users. The NCES data elements, on the other hand, are developed to a high level of specificity and are intended to be extremely flexible and encompass the widest possible use.

¹⁴ The SIF site can be found at <http://www.schoolsinterop.org/spec/Acknowledgements.htm>

¹⁵ The SIF data exchange specification can be found at <http://www.sifinfo.org/spec.htm>

¹⁶ An overview of the entire series on information management can be found at <http://www.ft.com/mastering/>

¹⁷ These reports can both be found at the National Forum on Education Statistics site at <http://nces.ed.gov/forum/publications.html>

Both of these efforts point toward the importance of standardized acquisition and the use of data for day-to-day and long-range decision making. The issue of standardization is particularly important when the focus is on evaluation. Increasing demands by outside funders and state and local agencies for data on program impact continue to raise the analytical burden placed on the district. In traditional transactional student data systems, the focus is on managing schedules and tracking attendance and grades. Reporting is designed using a top-down approach that is focused on district, state, and federal reporting requirements. What the NCES proposes is a much more flexible design that would support very fine-grained inquiry from any level of the organization.

An Example of Mismatched Rationalities: The MPS Case Study

Some of the problems one faces in a complex education institution can be seen in the following brief case study. The study describes how different organizational levels of a large metropolitan school district responded to the approaching deadline of a high-stakes assessment for its students at the end of eighth grade in the spring of 2000. The situational rationality of each major player led to radically different approaches and outcomes as the district struggled to develop an information system that would track students on their progress towards proficiency and that would accurately report student outcomes for retention and promotion decisions.

The District's Technology Strategic Plan

The practical implications of a robust systemic analysis framework are daunting. District officials were not unaware of this problem. In its *Technology Strategic Plan*,¹⁸ the planning committee outlined specific data needs for teachers and school administrators that are a direct result of district decentralization. The following excerpt from the report's Executive Summary outlines the technology needs of the three levels of the organization:

Classroom Management in a Decentralized Organization

Instructional time can be increased by reducing teacher time spent on classroom management tasks like attendance and grade record keeping. A single point of data entry (the teacher) should distribute that information across the school. New technology can then make available that data and integrate all other data relevant to a particular student to assist staff with decision making and the provision of services.

MPS has taken steps toward redesigning the student information database maintained at the district level. In addition, a site-based transaction-oriented database system is required. The two databases together can exchange relevant student information to provide better support.

School Management in a Decentralized Organization

Decentralization has imposed staggering new responsibilities on school management personnel at the same time that the complexity of client needs has increased. School-based technology will help address these challenges.

MPS Accountability in a Decentralized Organization

¹⁸ *Milwaukee Public Schools' Technology Strategic Plan*, December 11, 1996 (Rev. 02/01/97)
<http://whscdp.whs.edu/tsp/plan/>

Systemic integration of reporting data at both the school and district level is required to tie together school educational plans, school accountability measure reports, district monitoring reports (MPS report card), state reports, and federal reports.¹⁹

This portion of the strategic plan was then used to develop a Request for Proposal (RFP) for a new School Management System to enhance and extend the existing information system's capabilities. The two major themes of the *Technology Strategic Plan* and the RFP were "providing data to drive local and district decision-making" and assuring that the system "support school innovation by providing a tool that allows schools to implement their own initiatives and educational models."²⁰ These two goals imply an information system that is both a decision-support system that is linked to district and local goals, as well as one that has the capacity to design new data acquisition and reporting capabilities linked to local needs. Either of these goals by itself would have been difficult to achieve. Achieving them simultaneously would take both innovative programming and high-level training for the intended users in the schools.

The RFP laid out global system requirements that addressed some of the major shortcomings of the existing system. These requirements included an integrated security model, an import-export facility, and a user-friendly query-and-reporting capability. These prerequisites are important features that the present system lacks. The document goes on to elaborate on the current situation (at that time) and projected needs in all of the major data subsystems. The distance between the existing capabilities of the system and the projected end points were sometimes quite significant. One of the most positive elements of the RFP was the theme of data-based and data-driven decision making.

One of the major considerations to be faced in designing a database is to understand the questions that will be asked of the data. Much of the RFP is focused on improving the timely collection and reporting of student data: attendance, guidance interventions, discipline, and grades. It is also clear that data collected by the new School Management System (SMS) will be used to evaluate individuals, programs, and processes. The SMS system was purchased from a systems integrator and is being adapted to the needs of the district. The needs of the district require universal access—the ability to access a particular set of records from any location—and real-time longitudinal elements that track changes as they occur over time.

The shift from a centralized data storage and reporting system to a responsive, pervasive decision-supported system is a difficult challenge. The client/server topology recommended in the *Technology Strategic Plan* and required in the RFP provides a division between processing power and data accessibility that reflects the needs of actors at different levels in the system. The proposed system incorporates the two primary models of client/server system design. First, individual school administrators and teachers will be able to query the central data repository from their own computers. Second, the data queried can be downloaded to a local computer for further manipulation, or for combining with local data. The central data store might also supply "what if" datasets that allow for the development of contingency planning based on changes in important systemic variables.²¹ Most importantly, the system being developed will allow people

¹⁹ "The Impact of a Client/Server Architecture on Decision Support Systems," by M. Whitman and H. Carr, 1994, *The Executive's Journal*, 10, p. 8-9, 12.

²⁰ MPS. RFP-239. p. 0-3.

²¹ For more on this, see, for example, M. Whitman & H. Carr, *Information Strategy*, Winter 1994, Vol. 10 Issue 2, p. 12.

at a distance from the central office to become sophisticated consumers of student and system process data.

The Case of 8th Grade High Stakes

The decision to impose promotion requirements on 8th graders was made in 1997 as part of a larger change in the district's accountability model. The district was simultaneously engaged in a major effort to develop and implement proficiency testing in middle school both to encourage good teaching practices and to provide a broader range of assessments (in addition to standardized tests) to better understand and represent student learning. The district was also in the development phase of a district-wide technology strategic plan—begun in 1996—that had as a central component replacing older transactional systems for the day-to-day management of student records and building a data warehouse that would support site-based decision-making.

One of the important responses to the introduction of a multi-method assessment was the formation of the Middle School Principals Collaborative. The principals from 12 of the 23 middle schools initially formed this group. The group has since grown to include all middle school principals. One of the central duties of this group has been to work out the details of designing, implementing, and evaluating the proficiency standards and assessment structure of the district's middle schools. Over the course of the following two years, as the group grew to include all schools, the district and participating schools began to negotiate what metrics were to be recorded to demonstrate student proficiency. While several different methods were discussed, they all revolved around weighted averages of multiple measures.

At the district level, the units responsible for implementing the recently developed Technology Strategic Plan were building a number of new applications. Two of these efforts were of particular interest to schools. The first is called the Student Management System (SMS). The SMS was to be a new transactional system for managing student information. This would include enrollment, attendance, grades, discipline, program participation, and other elements. SMS was intended to replace a mainframe-based system—portions of which were over 15 years old. The other important school information system to be developed was a data warehouse for student assessment data. This system was intended to provide an analytical resource for studying programs, assessing school effectiveness, and generating reports for external accountability.

The intention was to make the SMS and the Data Warehouse available at all levels in the district. The distribution of the SMS from the district down to the classroom level was designed to accomplish a number of things. First, data entry was spread across a wider set of district personnel. Teachers would be able to take attendance in their classrooms and record assessment data directly. The teachers would also be able to check on student program status themselves. The system further allows teachers to record lesson plans and other data to capture more fine-grained data about classroom practices. Planners hoped to be able to integrate much of this data into the Data Warehouse for later analysis at higher levels of aggregation. This would make it possible to develop a better understanding of such factors as the impact of new curricula and changes in professional development.

The Data Warehouse was intended to provide local access to assessment and program participation data extracted from SMS and combined with test data from external vendors, referral data from special populations support systems, and other standalone data systems. System designers proposed developing different methods of interacting with the Data Warehouse that would support both differing data-use needs and differing technical skill levels of the system's users.

During this same period, we were working with staff members of the Office of Research and Assessment to help them develop their support for databased decision making in schools. Since much of our work is focused on the district level, we felt that it was also important to examine best practices for local data collection and manipulation. To this end, we have been working with Derek Mitchell of CRESST²² and the Quality School Portfolio (QSP)²³ to consider the critical elements of good, school-level, information-system design.

On April 26, 1999, we participated in a districtwide review of the status of the MPS Student Management System and Data Warehouse projects. At this meeting, we also presented the QSP tool as an additional approach to school-level student data management. MPS deputy superintendents, all department heads, and representatives from the University of Wisconsin-Milwaukee and Alverno College attended this meeting. The meeting covered the actual progress to date of the ongoing design efforts, as well as the pressing data needs of Milwaukee's middle schools. Representatives of the Middle School Principals Collaborative also presented their homegrown approach for tracking student progress. This initiative was developed as a direct response to the district's inability to deliver the needed data in a timely manner. One important outcome of this meeting has been the growing sense of urgency regarding the delivery of useful analytical data for decision making at the school level.

The QSP presentation served to provide both a background for discussing the needs of site-based decision making and an overview of information-systems planning across the district. The major areas of thrust behind QSP (school action plans, reporting processes, data-based decisions, and accountability) are by no means unique to this software package and reflect the needs of site-based decision makers in any field. We discussed how QSP might be used to accelerate the development process of the Data Warehouse by providing a conduit through which site-based managers could funnel back their own analytical models. We discussed our interest in the research on how schools store, analyze, and retrieve data in support of continuous improvement and other school reform models.

There were three significant outcomes of this meeting. First, the director of the MPS Department of Technology Services committed to getting all of the middle schools wired and hooked up to the SMS system by October 1999. He also committed the application development team to building and fielding a system for capturing and reporting the middle schools proficiency data that would be used to make promotion decisions for students who would be 8th graders in the 1999-2000 school year. The second outcome of the meeting was the decision of the Middle School Principals Collaborative to continue the development of its own school-based system in

²² CRESST (The National Center for Research on Evaluation, Standards, and Student Testing) is located at UCLA. <http://www.cse.ucla.edu/>

²³ More information on the QSP can be found at <http://qsp.cse.ucla.edu/>

the event that the district would be unable to continue. The leader of the effort expressed concern that relying on the district to build and deliver a system in such a short span of time would be difficult.

Finally, the most important outgrowth of this meeting was a decision by the director of the Office of Research and Assessment for that office to build its own analytical database. This decision was driven by two different concerns. First, there was the recognition that a number of schools were under pressure to make decisions about preparing students for upcoming high-stakes assessments. Neither the existing mainframe system nor the new Data Warehouse being implemented has the capacity to provide the level of flexibility in reporting needed by schools. Second, there has been a growing realization that meeting day-to-day, operational data needs and answering questions about accountability require different interface, data-storage, and data-manipulation technologies. In MPS, this gap between operational and research needs has led district research staff to face the necessity for developing a different data management architecture to support these separate efforts.

At this point, there were potentially three different systems that might be in place by the end of the 1999-2000 academic year to track and report on the promotion status of 8th grade students. What was unknown at the time was that the recently elected (April 1999) school board was about to replace the superintendent. One month later, a new superintendent was in office; he replaced all but one of the department heads (the director of Technology Services retained his position) and one of the two deputy superintendents. In addition, the director of the Office of Research and Assessment was moved on the organizational chart to report to the director of Educational Services rather than to one of the deputy superintendents. These changes at the district level both halted the plans for the creation of a separate research data system and challenged the leadership of the technology services unit so that neither group was able to accomplish its goals for supporting the 8th grade graduation decisions. By the end of September 1999, both units formally informed middle school principals that they would not be able to provide any help in collecting or reporting student progress towards meeting graduation requirements, nor would they be able to do anything more in reporting on student retention. All middle schools were going to be responsible for notifying high schools of the status of each student at risk of not passing by the end of the summer school session.

Despite the political and technical upheaval occurring at the district level, the Middle School Principals Collaborative was continuing to meet to discuss tracking student performance and reporting student progress towards promotion to teachers and administrators. The middle school principal who had developed his own system for tracking this information formally offered his system to the group and agreed to both modify the system to fit several different school organization models and to train a small number of people to provide training support in turn to their counterparts in other middle schools. This effort was designed to use existing hardware and software and would run on either Windows or Macintosh computer systems. It was also designed with the expectation that it could be combined on a central server and managed by either the Principals Collaborative or some unit at the district level. The system went through several formal reviews and revisions and was used at the end of the school year to produce electronic files that were sent to the district's Office of Research and Assessment for review. These files

were then uploaded to the Data Warehouse for use this fall to generate statistics for the district's accountability report.

The most serious dilemmas encountered by participants in these development efforts were not technical. The district had not completed its connection of the middle schools to its high-speed network, but the amount of data that needed to be communicated was trivial. The barriers all revolved around communication. As the end of the school year approached in the spring of 2000, I was asked by the manager of application development in the Technology Services department to become a formal member of the Data Warehouse development team. The team is explicitly responsible for making sure the warehouse contains the data necessary to produce the district's annual accountability report.

My involvement was partially based on my knowledge of desktop hardware and software, but the primary reason the team leader wanted me to participate was to overcome the communication barriers between the Department of Technology Services and the Research and Assessment Office. I was also the only person on the committee who represented school-level interests through my involvement with the two middle schools I was helping train to use the QSP tool described above. It became clear half way through the first meeting that the group had not developed a common understanding of the needs of the schools or of the limits of existing data systems in meeting the district's accountability needs. I was disappointed (but not surprised) to find that the Data Warehouse team did not include, nor had ever included, a school administrator.

The team worked over the next two months to put together a plan for collecting the school-level data and putting it online. We also identified an alternative method for collecting the results of the summer school assessments of students who had not passed by the end of the regular academic year. The mix of technologies included installing the standalone system developed by the Middle School Principals Collaborative in all schools with 8th graders and requiring them to use it, repurposing a dormant mainframe system to collect alternative assessment data on summer school students, writing custom programming to aggregate the school data and load it into the Warehouse, and creating a new report on a discontinued report card system to provide high schools with accurate placement data for students who were or who were not retained in grade at the end of summer school. While the process was successful in the end, the resources used to respond to this emergency reporting need could have been better spent in other areas if the district's data management system had been in synch with the accountability requirements the educational system had placed on schools and students.

Preliminary Conclusions

Knowledge management is such a wide-open area of study that it is difficult to understand the implications of these models of knowledge management for an educational setting. One thing seems certain. School information systems are one of the most difficult to harness because they often lack any overall rationality for cooperation and compliance. Differences in data needs and uses across different organizational levels present significant barriers to the collaboration necessary for innovation in knowledge management.

The case study cited above points to a number of different areas for concern. First, ambitious systemic reform efforts call for radical changes in traditional school information systems. The dimensions of knowledge management strategy that Marchand maps out in Figure 1 provide a background for the difficulties MPS managers encountered when they attempted to make a sweeping overhaul of their information technology infrastructure. Even the most conservative deployment estimates of system designers in the original Technology Strategic Plan are more than two years in the past. The SMS system, which was slated to be rolled out for all schools in 1999-2000, exists in only twelve of the eighteen high schools. Developers estimate that it will take another two years to complete the wiring and programming necessary to bring all 160 regular schools online. Some managers have indicated that the declining political support for the system will probably lead to the development of a new system independent of the externally purchased SMS application currently being implemented by Milwaukee high schools.

The Data Warehouse is also several years behind schedule. There remain two major stumbling blocks to the development and use of the system. The first hurdle is the difficulty of producing assessment, enrollment, and program participation statistics that match those created by the existing combination of mainframe exports, SAS (statistical software) scripting, and hand manipulation used to produce the district's accountability reports. This problem can be traced back to the inherent complexity of the analytical puzzle of tracking a highly mobile population of students with an archaic information system that relies on a great deal of expert knowledge on the part of its users. This is simply a high-dimensional analytical problem that cannot be easily moved from one system to another. The other problem is that the new data system uses different data element definitions, field layouts, and formats. The new system is designed to take into consideration the improvements in methodology and changes in how one defines important school metrics such as value-added assessment and program effectiveness. Any comparison of analytical models between the two methods of producing accountability statistics requires the ability to engage in a sophisticated translation among approaches that are vastly different.

The other stumbling block the Data Warehouse faces is the method of access that school administrators and teachers will use to extract data for local analysis. The tool that was initially adopted is being used by district-level analysts in the Department of Technology Services and the Office of Research and Assessment, but was seen as too complicated for the average or casual user. Other solutions that rely on Web-based access are either not supported by the desktop technologies, do not meet the security requirements the district must meet to protect student data, or are as complex as the tool the district is currently using.

Finally, the lack of strategic planning and strategic resource allocation continues to plague development efforts at the district level. It is possible to raise funds to support the infrastructure in providing high-speed video to several thousand classrooms, but it is difficult to find the resources to train the staff to use video effectively, or to build an evaluation system to track the impact of this technology on teaching and learning. It is the mismatch between resources available for high-profile technologies and the resources available to measure effective teaching that lead to the dilemmas encountered by Milwaukee Public Schools. The level- and unit-of-analysis problems alluded to above only exacerbate this mismatch between resource availability and needs. When both resources and the external requirements for annual accountability focus

development efforts on the introduction of newer and newer technologies, school-level needs are bound to be shortchanged.

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Education System Information Needs and Systemic Reform

Jeffery Watson and Susan Zeyher

Abstract

This paper argues that systemic reform initiatives require that schools and school districts become more able to use data to inform decision and policy making. Furthermore, in anticipation of increasing demand for sophisticated information tools, this paper provides a framework for analyzing information systems from a systemic reform perspective. The four major dimensions of this framework are: user needs, data characteristics, analytic structures, and technical requirements. The dimensions of user needs are examined through published literature that describes how education professionals use data and information. The data characteristics dimension identifies the major attributes that optimize the utility of data. The analytic structures dimension describes ways in which data are processed and understood. Finally, the technical considerations section identifies issues related to the implementation of information systems in general. This analysis supports the conclusion that information systems aligned with systemic reform must provide all users with access to data that are useful to their particular job role.

Introduction

In the last decade of the twentieth century, systemic reform rose as a major focus for educators and education policy makers (Vinovskis, 1996). The impact of any major reform or change effort will be varied and far-reaching, but, in general, systemic reform initiatives call for a tighter coupling between components of an educational system and student learning. In his review of systemic reform efforts, Vinovskis reports that systemic reform usually entails either a push to deliver a more coherent and curriculum-driven effort, or an attempt to improve educational and social services for school aged children (Vinovskis, 1996). The focus of this paper is to look at how information can be conceptualized in support of systemic reform efforts.

Reform in its broadest sense implies that some group of individuals is interested in *steering* a process or system from the present state of affairs to a different and hopefully improved state of affairs. Assuming that operators (i.e., the people trying to steer the system) know how a system works and how to steer it, the underlying process of reform involves four basic steps: measuring the current state, comparing it to the desired state, and taking action to reduce the difference between the present and the desired state, and reassessment. Reiteration may be necessary. For example, let us look at a situation where the goal is to improve seventh grade mathematics scores. The first step is to assess current student performance through some measure. Secondly, we must identify strategies to improve the scores and implement them. The next step is to reassess pre- and post scores and compare them with the performance goals, then decide whether or not to make further changes.

The iterative process described above is the basis for understanding information flow within an educational system. One recurring argument throughout this paper is that the frequency at which the cycle is repeated is an important factor in determining what are the information needs of the system and how an education system can effectively use information. Figure 2 is a simplified

diagram that shows how information flows through a school. Note that at the classroom level, where instruction and assessment take place, the frequency for making strategic interventions is higher than at the administration level. The reason for this lies in differences between stakeholders' organizational roles within the local and district educational systems. Where teachers focused daily on individual students, school administrators must view performance over time and often across groups of students.

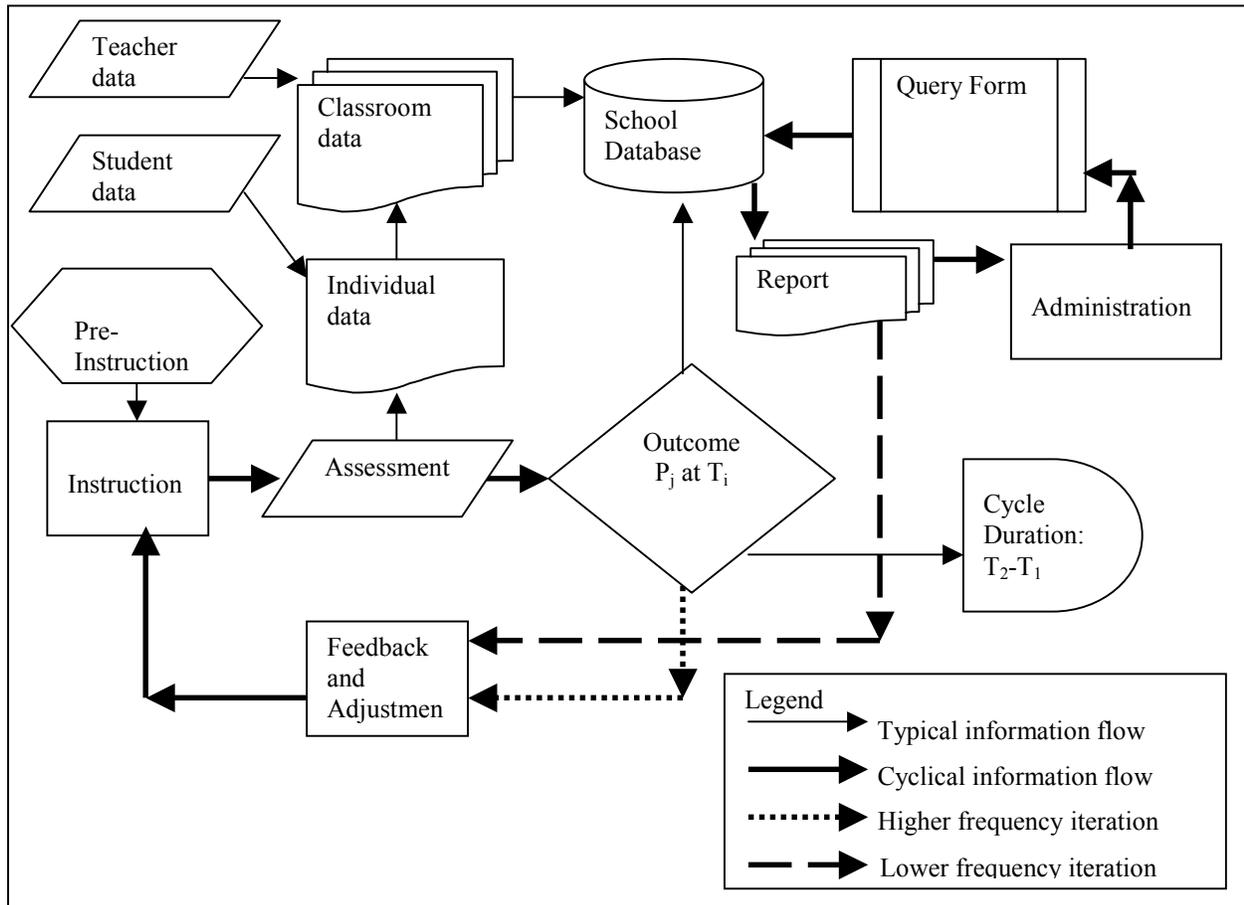


Figure 2. This diagram represents information flow within the context of education decision-making. It also indicates how various stakeholders can make decisions concurrently at different frequencies.

The process depicted above represents how data, numbers such as test scores and attributes, are transformed into information and knowledge (see Thorn, this volume). Information is created when data are placed in a context such as when reports are made from the school database. Knowledge is acquired when information is interpreted through the eye of experience, such as when an administrator reads the report, develops some hypotheses, and submits other queries to refine her understanding of the situation. At the root of any reform effort is the implicit need to manage all three forms: data, information, and knowledge. This is especially true if we assume that operators (administrators, teachers, and others) do not know, with 100% certainty, how a system works, thus, how to steer it.

An accurate conceptual model is helpful to examine the effects of various procedures upon outcomes. In this case, the model represents how data and information can inform not only the implementation of change through feedback and adjustments, but also contribute to knowledge about how the system works by tracking the flow of data and information through the system. For this paper, we take the view that the process of education is not a perfectly understood system and that much of data analysis in education is devoted to trying to improve the precision of various models of learning and educational theory (Gaynor, 1998).

A review of the educational research literature indicates that there is general agreement on the types of data that are useful for improving schooling. Johnson (1996) argues for only two basic purposes of data in addressing school improvement, profiling schools and informing instructional decisions. Speakman suggests that three types of data are needed to accomplish those purposes: student data, business data, and outcome measures (as cited in Fickes, 1998). Bernhardt (1998) extends this model by suggesting three similar categories --demographics, school processes, and student learning-- as well as adding a fourth data type for perceptions. She goes on to link the ways in which different combinations of data types can describe the effectiveness of various programs. For instance, data that represent the interaction of demographic, school processes, and student learning should reveal, among other things, whether or not there are differences in how various student groups are experiencing school (Bernhardt, 1998).

The types of data researchers, administrators, or educators deem as necessary and sufficient for analyzing education problems and performance depends on how these users conceptualize or think about the education process. Therefore, for an information system to be useful across all levels of an education system, it must support the data and information needs of those in different roles. Furthermore, strategies vary in how reform is implemented (Vinovskis, 1996) and will differentially influence the information system. Some reform initiatives are top-down, district, or even state-driven efforts, while others emerge at the school or even classroom level. These reform implementation issues are too complex to fully describe here; but in general, ideas and strategies for implementing reform arise at all levels of education. In fact, successful implementation may depend upon blending both top-down and bottom-up strategies (Fullan, 1994; Clune, 1993). The nature of the information system for analyzing the success of the implementation will be greatly influenced by what approach is taken.

In summary, information systems and tools fill a critical need for education systems that is likely to increase in the near future. In anticipation of the increased focus on the use of information systems in education, we identify four major dimensions for comparing information systems and tools applied in an educational context. These dimensions are designed to differentiate between any two systems or tools. The first dimension, *user needs*, is important because systems and tools vary in whom they target as intended users. That is, information systems can be evaluated on the basis of how well they meet the needs of potential users. The dimension of *data characteristics* encompasses considerations associated with using large datasets within large organizations. This dimension is intended to identify differences in how a system or tool manages and structures data. The third dimension, *analytic structures*, identifies the different ways in which information tools and systems approach data analysis. The final dimension, *technical considerations*, differentiates information systems on the basis of system and technical design characteristics.

Technical considerations are also important when comparing two ostensibly similar systems, or when budget become a major design constraint.

User Needs

From a systemic reform perspective, one method for distinguishing an information system is to describe the major user groups of an education system and then determine how well an information system or information tool meets the needs of those users. Identifying the ways in which educational professionals use information is critical in evaluating the effectiveness of various systems or tools that might be employed. In fact, it is very difficult to meet informational needs without clearly understanding how user needs change (or remain constant) across and within user groups. For the purposes of this paper, we have identified four sets of users in a school district: students and parents, teachers, school administration (including their support staff), and district administration. The following section identifies user groups and describes examples of their respective information needs.

Students and Parents

The primary information needs of students and parents is to monitor student progress and performance. The use of data by students and parents seems largely ignored in the literature, but it is reasonable to expect that data could be used in many ways. Examples include, but should not be limited to, the following: monitoring progress, deciding how much time to spend on homework or other extracurricular activities, initiating tutoring or teaching meetings, deciding future course selection, and career guidance.

Data that are available to students and their parents have traditionally been in the form of report cards, progress reports, and classroom performance on homework and examinations. Members of this group use data on individuals and that vary in temporal resolution; for example, sometimes parents and students look at performance that reflects work for a very short period of time (daily homework, weekly quiz), but performance over longer periods of time is important as well (semester and yearly grades).²⁴ As districts become more sophisticated in how they track student performance, students and parents will be able to monitor progress in new and innovative ways.

New types of information that will prove useful to students and parents should develop as schools and school districts begin to develop more sophisticated information systems. For example, the Maryland School Performance Assessment Program (MSPAP) is meant to provide feedback about school performance (see <http://www.MDK12.org>). Its assessment techniques, though not designed to measure individual student performance, are aimed at measuring how well each school is doing. This information is made available to parents (and principals) who can then take action as needed.

Teachers

Teachers' information needs are difficult to summarize; however, several trends are worth noting. First, teachers vary greatly in the types of information they find useful. Obviously,

²⁴ The issue of temporal resolution is discussed in greater detail in the data characteristics section.

teachers rely on individual grades and assessments, but some may also tend to use intuition or tacit knowledge (see Thorn, this volume) as well as other inferential types of data (Bernhardt, 1998). In addition to working to improve individual student performance, teachers may also be concerned with improving their teaching methods in general. Teachers may therefore need data that are not based solely on individual students' performance. Instead, teachers may want to compare two groups, each of which received a different treatment, such as a different classroom demonstration or activity (for a formal example, see action research methods as described by Johnson (1997)). Finally, teachers vary in how willingly they embrace the use of data captured in an information system within their classrooms. Justifiably, some teachers have an inherent fear that data could be used by administration in a punitive or judgmental fashion.

Despite variation among teachers, there are some important considerations regarding the information needs of teachers. First, their focus is on individual students or on a subset of their class rosters (Johnson, 1997). Since a teacher's goal is to teach individuals, aggregate data is of limited use, except for perhaps comparing two groups of students, or a single group of students across time. Regardless of whether or not a teacher aggregates data on classroom performance, she will ultimately be concerned with applying knowledge and information back to individual students (Johnson, 1997; McLean, 1995). Action research techniques provide a well-documented process that highlights how data can be used in the classroom. In general action research methods focus on a subset of students over a very short period of time. Johnson (1996) writes:

Each data-collection cycle and its results should not be thought of as an activity with a grade...it should be thought of as information on the progress being made toward attaining the collective goal and to assist all members of the organization as they make decisions for current and future action. (Calhoun, as cited in Johnson, 1996)

Finally, teachers have a common information need in that they use data that have temporal resolution ranging from daily to yearly. The reason for this is that teachers focus on individual student learning and while year-end assessments are important for advancement and compliance, it is the more frequent assessments that enable teachers to track and project student progress. In fact, year-end assessments provide teachers with little time to improve student progress because by the time tests are scored and analyzed, the year has ended.

School Administration

At the level of administration, user needs are very different from those of the stakeholders in the classroom. The information needs of school administrators encompass data concerning business operations such as transportation, planning and budgeting, purchasing and supply management, accounting, and others (Drake & Roe, 1994). Also, schools often track attendance, test scores, national test scores, and surveys of students, staff and parents (Johnson, 1996). The amount of data that exists at this level is staggering and can quickly overwhelm even the most well equipped administrator, resulting in the need for better and smarter analysis tools.

One way of understanding how school administrators utilize data is to understand how data can be used as a management tool. First and foremost, data can provide a portrait of either a school's profile (for example demographic breakdown, number of students, etc...) or a snapshot of that school's overall performance. As an administrator repeatedly uses data over time, data can also

indicate change from which school improvement can be inferred. Furthermore, longitudinal snapshots can help administrators estimate whether or not school goals are likely to be met. Data can also be used to inform decisions. Namely, data can indicate what (if any) implementations are needed at the school level to help ensure school success. Repeatedly using data to inform decisions will impact administration's conceptual representation of the school and its systems.

The problem with using data in these ways lies in the fact that often, school administrators do not have the time to collect appropriate data or the tools with which to analyze available data. Modern information tools promise to fill this void, but as of yet this is largely an unanswered challenge. For now, school administrators must first make sure that they meet internal and external reporting requirements. This kind of data use will most likely result in the school using data that is in line with district or state requirements, such as proficiency or Title 1 reporting.

However, school administrators, like teachers, are often interested in individual student data and performance, requiring records to include data that have not been aggregated across individuals. Yet there is often the need to compare groups of students, resulting in the need for a slice of data in order to find meaningful information. Likewise, while data are often more useful when the temporal resolution is longer than six months (Drake & Roe, 1994), there may be need to look at data that capture performance over a period of days or weeks (McLean, 1995; Bernhardt, 1998).

District Administration

When compared to school administration needs, districts are less concerned with individual performance, and more concerned with demographic and performance data aggregated across individuals and schools. Districts also have less need for data that measure performance over a short period of time. According to Wallace as cited in Johnson (1996), districts gather much more data than they can hope to use effectively, unless they institute the means for tracking changes in a systematic way. Many districts need techniques for turning data into useful information. Furthermore, districts must also be concerned with legal data, compliance data, long-term financial planning data, statutory requirements, and Title I data to name a few.

As far as *how* data is used by districts, a few general observations can be made. First, districts must operate within several different sets of requirements. Therefore, data are used as information within the context of steering the district to success. In general districts use data to inform the current status of schools and then try to anticipate where resources should be spent to maximize future success. This process is similar to those describe in school administration roles, but are different in that districts typically measure school performance yearly and implement interventions in time scales of a year or more.

Data Characteristics

This section describes data characteristics that impact the implementation of an information system as well as its utility. In other words, what are the primary concerns when collecting, storing, and using educational system data? This section discusses four topics: *records*, *metadata*, *grain size*, and *temporal resolution*. The basic element of any database is the record. In educational databases, records often contain information about a particular student, although

records can also be organized at some other level (e.g. teacher or school) or event (e.g. discipline referral records). Metadata is useful for many reasons, but primarily because a metadata schema will organize a set of records in a meaningful, and hierarchical way. Good metadata practices will increase the usability of a database. Grain size and temporal resolution refer to what extent aggregation occurs within a database. Grain size refers to the number of students aggregated in a data set, whereas temporal resolution refers to the practice of aggregating over time.

Records

The basic units of any database and information system are data records, which are comprised of data elements and their attributes. The element is the data value of interest (numerical, category, etc...) and the attributes are associated values that further define the data value. Furthermore, attributes often utilize a controlled vocabulary; for example, a data record may be a single student's mathematics score on a district-wide assessment. The score itself would be considered the element, and the student's name, identification number, age, ethnicity, grade, would be the attributes. Some attributes may have nested attributes associated with them; for example, the name attribute could be broken down into first, middle, and last. Furthermore, some attributes may also be data elements, such as student identification numbers.

Metadata and the Organization of Information

Metadata is defined as information about data. Metadata does for electronic information what the library classification system does for printed information. At the very least, a metadata schema organizes data into an interconnected structure, so the context and description of the data can be easily seen (Ferdinandi, 1999). This is accomplished via hierarchical indexes of terms and definitions that describe data fields and records. In addition to describing data, metadata can fill other roles as well. Administrative metadata such as acquisition and storage location information facilitates the management and administration of a database. While technical information such as file formats and software documentation help describe the operation of an information system. Metadata are also created as data are accessed. Use and user tracking can inform system developers how users are currently utilizing the system. Finally, for certain collections of information, the metadata schema will include information about the condition of the resources within the system. This could refer to back-up procedures or in the case where the original data is in paper form, where and how the original documents are archived (Gilliland-Swetland, 1998).

Using metadata to organize data elements and attributes in a comprehensible way is, for humans, an important interface issue. A good metadata schema can organize data and create a well-defined search vocabulary. Computers can search large amounts of information in seconds, but humans cannot. Metadata creates a hierarchical system of categories into which data elements are sorted. We can use metadata as a search vocabulary by giving clear definitions to the metadata terms used to label the categories.

Metadata defines the organizational structure of the data elements. It creates categories into which like elements are grouped together. For example, the National Center for Education Statistics (NCES) has developed a hierarchy of data elements for a school information system, one category of which is designed to accommodate assessment data. Table 1 below indicates the

various levels of organization, as well as the specific data elements, that might be used to describe any given assessment score. The metadata categories act like large boxes inside of which metadata subcategories or small boxes exist. Within the subcategories are the data elements and attributes. The elements in this example are: purpose, assessment type, assessment title, assessment content, subtest type, level. Purpose and type both have anticipated attributes that describe the range of possible values. The metadata categories create an organized structure.

Metadata Category:	Metadata Subcategory:	Data Element:	Attribute
ASSESSMENT	Assessment Information	1880 Purpose	01 Admission
			02 Assessment of Student's Progress
			03 Development of individualized educational program (IEP)
			04 Development of individualized family service program (IFSP)
			05 Diagnosis
		1890 Assessment Type	01 Achievement test
			02 Advanced placement test
			03 Alternative Assessment
			04 Aptitude test
			05 Attitudinal test
		1900 Assessment Title	
		1910 Assessment Content	
		1920 Subtest Type	
		1930 Level	

Table 1
Part of the NCES Metadata Organization for Assessment Data

NCES Data Elements

The National Center for Education Statistics (NCES) identified 345 basic data elements for student information systems. “Each data element refers to a particular aspect of student data for which some need was perceived within the school system” (U.S. Department of Education, 2000, p. ix). NCES compiled a list of the possible elements that could be used in a school information system, so educators could select for themselves the relevant data elements for their system. They developed *The Student Data Handbook: Elementary, Secondary, and Early Childhood Education*, which

... provides guidelines for designing student record keeping systems for use by schools, school districts, state education agencies, and other educational institutions. Included is a

discussion of the benefits of a well-designed student record system, as well as potential uses of such a system at the school, district, or state level. Also included is a description of a step-by-step process for designing an effective student record system (NCES, 2000, p. viii).

NCES anticipates that the needs and uses of data may change over time, so it suggests a procedure for updating the system. “However, as data needs change from year to year, a process has been developed to allow for annual updates based on the needs of educators” (p. 3). The handbook recommends a process for selecting and using the data elements, along with a process for making annual changes. “The reader is encouraged to use this handbook, and the other related documents, as a tool for making appropriate decisions about how and what data should be collected about students” (p. 3). Appendix A contains a condensed outline of the NCES Data Elements and the Entity List (U.S. Department of Education, 2000). There are categories, subcategories, data elements and entities, all with definitions given in the handbook. Items A-I are the metadata categories of the hierarchy. The metadata subcategories divide the categories and contain the 345 data elements themselves. There are twenty-four entities, which give context to the data elements (U.S. Department of Education, 2000, p. 27), where entity refers to a person, place, event, object or concept about which data can be collected. The categories, subcategories, and data elements are hierarchical groupings with unique names. The data elements and entities also have unique numbers. “When entities and data elements are combined, new unique data elements are created. For instance, the data element Last/Surname is defined each time it appears, but the corresponding entity is different for each appearance (e.g., Student or Parent/Guardian)” (p. 11). Some data elements have data attributes, which are sets of controlled vocabulary terms that are the accepted definitions for the data elements.

Grain Size

Grain size refers to either the number of students that is represented by a data element or attribute; or, in some cases, grain size might also refer to whether or not the data element reflects the total score of an assessment, or a subset of items from a particular assessment. Therefore, data that have a smaller grain size represents fewer students (or fewer items). For example, Milwaukee Public Schools (MPS) uses the Wisconsin Student Assessment System (WSAS) to assess mathematics achievement for grades 4, 8 and 10. In its accountability report, MPS describes yearly mathematics achievement scores by school and ethnic group for these grades. This is a fairly large grain size, which is suitable for district-wide accounting purposes. The grain size could be further reduced, however, by also tracking student, teacher, socioeconomic status, and many other potential indicators for school improvement. Another way in which the grain size for this particular assessment could be reduced involves recording sub-scores. For the grade 8 achievement test, WSAS uses the TerraNova Mathematics Computation test, which utilizes two sub-scores, Mathematics and Mathematics Computation. The idea in reducing grain size is for the resulting dataset to be analyzed in greater detail and for the data to be useful to a wider range of users.

However, it should be noted that as grain size decreases, the demands on the information system increase, such as more time required for data entry and analysis. Additional physical and network resources must be devoted to transmitting and storing data as well. Therefore, the gains of

maintaining a fine-grained database must be weighed against the costs. As a matter of practice, the usefulness of data is determined in part by the number of ways in which it can be broken apart (Ferdinandi, 1999). It becomes impossible to compare and contrast groups at a level lower than the grain size supported. For example, if a district is storing the performance data of students as the aggregated value across grades and schools, then it is impossible to compare the performance of groups of students within schools. However, if the district stores data at an individual grain size, then these comparisons are possible.

Research methods encourage, and often require, individual-level analysis of performance (McLean, 1995; Bernhardt, 1999). The rule of thumb here is to use the smallest possible grain size, while ensuring that at some point each data record can be traced back to an individual student or teacher. This ensures that if records are aggregated, they can be disaggregated down to the smallest possible unit. Doing so ensures that the user will be able to reach a fine enough detail to be able to define new groups of students for analysis.

Temporal Resolution

Temporal resolution refers to the length of time represented by a data element. For instance, a quiz probably reflects student performance over a period of a few days or less, whereas a statewide assessment tries to measure performance over a year or longer. The way an information system accommodates temporal resolution heavily influences the information system's design and capacity. As the temporal resolution of data decreases, the demands on data entry, processing, and storage greatly increase.

The best method for improving temporal resolution involves increasing the sampling frequency (i.e., reducing the amount of time between measurements). For instance using weekly test scores instead of a single cumulative test score. As with grain size, action research literature provides an excellent example of why and how educational professionals such as teachers and school administrators might require data with very fine temporal resolution (McLean, 1995; Johnson, 1997).

Analytic Structures

While the previous two sections are concerned with issues relating to the collection and organization of data; this section focuses on issues concerning the analysis of data. This section lists and describes the possible analysis methods for large datasets. The degree to which information systems and tools support these analytic structures varies.

Queries and Reports

Datasets almost always have more data that a user is immediately interested in analyzing. Therefore, the first step to analyzing data is to query the database. This process involves creating a set of instructions that extract specific records and fields out of the database. Ideally, the database or information system interface should allow the user to navigate around the database without knowing any database language (Ferdinandi, 1999). Furthermore, identifying the

appropriate records and fields often depend on good documentation that defines what records are available and what each element represents.

Querying usually consists of a relatively straightforward process. Identifying the appropriate database or data table is the first step in creating a query. Large information systems usually integrate several databases that vary in technical sophistication and types of information (see *Technical Considerations* section). Once access to the database is established, the user will want to select appropriate data fields as well as define any limits and/or logical arguments. Defining limits and logical arguments allows users to query specific groups of records, which makes the analysis and extraction process more efficient. Finally, the user will most likely want to view or group only various aspects of the extracted dataset. For example, a middle school principle interested in extracting grade 8 mathematics scores from a district-wide information system would need to complete the following generic steps.

1. Identify where mathematics scores are kept and use a database query tool to connect to that database.
2. Choose to extract mathematics scores, student identifiers, demographic data, and other fields that are expected to inform the overall picture.
3. Limit mathematics scores to only those of students in grade 8 and those students who attend a specific school.
4. Group students according to meaningful characteristics such as low scorers versus high scorers.

The above process will most likely result in a list that includes student information such as name and student identification number, grade 8 mathematics scores, and various pieces of demographic information. Analyzing such a list is the focus of the rest of this section.

Aggregation

Aggregation and disaggregation represent vital analysis functionality (Johnson, 1996; Bernhardt, 1998). Understanding and working with data at the appropriate grain size and temporal resolution is critical for users. These functions allow users to create data elements that are appropriate for their needs.

While educators may be able to derive some insight from raw numbers, much greater benefits can be achieved when information is broken down, or disaggregated, across the school population. Data are often broken down by grade, race, SES, and gender. Data processed in this way reveal previously unseen patterns and trends. (Johnson, 1996, p. 14)

Without the ability to aggregate, or disaggregate, users become limited in the types of questions they can answer. For example, a teacher interested in conducting action research requires data at the individual grain size and of very small temporal resolution. District-level data that are aggregated to the school-level grain size will be useless. In addition, disaggregation provides insight into what problems exist within an educational setting. It may be more accurate to think

of disaggregation as a tool for problem identification, than as a tool for problem solving (Bernhardt, 1998).

It should be noted that the extent to which you can aggregate is limited to the depth of the database hierarchy. A database that has a flat organization, where data elements are not organized by metadata structures, does not lend itself to a high degree of aggregation or disaggregation. Consider the MPS WSAS example: During the scoring of this assessment, student performance is measured and stored at the item level by the test provider. This information is reported back to MPS staff members, who then must decide how to store the information within their database. If MPS utilizes a metadata structure that nests WSAS mathematics scores within other mathematics assessment scores, it becomes possible to aggregate *all* mathematics scores into a more general indicator of mathematics education. For this particular example, assume that MPS has the capacity to store the item-level performance per individual student. Performance per school would be calculated by aggregating across individuals. Performance per measure, Mathematics, for instance, would be aggregated across items. Performance-per-measure-per-school involves aggregating across items and individuals. More than likely, these aggregate values would be computed and then stored as separate data entries. However, if WSAS data were stored only as aggregate values, disaggregation below the school level becomes impossible.

Multi-Dimensional Graphing

Since large datasets are multi-dimensional, creating graphic representations can be challenging. Anticipating the best way to graph data becomes much more difficult as the number of graph options increases. Yet patterns and trends are more salient in well design graphs. The basic problem is that as the number of dimensions increases, the number of possible three-dimensional graphs increases exponentially. An important analytic function is the ability to create dynamic figures and documents that change as the user not only drills up and down hierarchical dimensions (aggregation), but across dimensions as well. It is unwieldy to predefine all the possible ways a user may be interested in presenting or exploring a set of multi-dimensional data. For this reason, because it is impossible to tell which of these graphs may be useful to potential users, some capability should be provided to allow users to create and view multi-dimensional graphs on an as-needed basis. There is considerable variation in how well various vendors support this analysis approach (Ferdinandi, 1999).

The importance of having a meaningfully organized dataset cannot be stressed enough. Organizing a dataset provides the user with a natural set of dimensions to graph. This reason alone justifies using metadata for organizing datasets. The categories and subcategories provide users with natural and meaningful dimensions along which to view and analyze data. Consistent metadata use optimizes the number of ways in which different data elements can be used together. For example, consistently applying metadata labels to multiple mathematics assessments will make it more likely that a user could generate reports or graphs that compare student performance across these various measures.

Statistical Analysis

Up to this point, all of the analytic structures mentioned are simply aimed at identifying trends within data. However, given the noisy nature of human data, it is often desirable and necessary to show that a trend is statistically reliable. A variety of statistical analyses exist that may be useful for this purpose (Ferdinandi, 1999). At the minimum, users should be able to perform basic comparison analysis, such as a t-test, X^2 , or analysis of variance. One important function provided through ANOVA is the ability to identify significant interactions, which are very useful in understanding how education efforts are impacting the population in different ways (Bernhardt, 1998). Also, applying correlations or multiple regressions may be appropriate with certain sets of data, such as longitudinal data. It is important to note that the usefulness of statistical analysis depends a great deal on the grain size and temporal resolution of the data. In general, the more sophisticated software tools such as SAS and SPSS can be used to query databases, but require a level of sophistication by the user.

Data Mining and Model Forecasting and Prediction

As the introduction of this paper argues, it is believed that one purpose of an information system is to allow professional evaluators to improve the way in which they model the educational system and its sub-processes. This process involves problem identification, hypothesis formation, implementation, and data collection and analysis (Bernhardt, 1998, p. 144). However, as noted earlier, schools and districts tend to collect more data than they can possibly utilize. Data-mining tools are designed to facilitate problem identification and hypothesis formation from datasets that are already collected. Data-mining tools provide users with streamlined methods for identifying interesting and useful trends within a dataset. Data-mining techniques vary but in short they attempt to automate or predict hypothesis generation. These techniques include using decision trees, statistical analysis, data visualization, and neural networks, all of which are built to uncover significant factors involved in outcome variation (Ferdinandi, 1999).

Technical Considerations

This section discusses the major technical issues related to implementing information tools and systems within an educational system. The first issue addresses the degree to which a given tool adopts user centered design principles. This is a significant variable in understanding how a tool will impact an organization at the individual user level. It is considered a technical issue because the usability of a given tool is determined by the developer's emphasis on adopting user centered design practices (Baecker et al., 1998) (Schneiderman, 1998). Also, the interface design and overall usability of a tool will be a significant factor in whether or not the tool is successfully integrated in the daily practices of its intended users. Another technical issue is concerned with identifying how a tool is designed to interact within a technological environment. Successful diffusion requires integration throughout an organization's pre-existing software and network infrastructure. Client-server relationships are an important consideration as is the underlying database design. Both operational and relational database designs are appropriate for very different types of applications and it is important to understand these differences when classifying information tools. When discussing actual hardware requirements, care must be taken *not* to confuse *possible* implementation strategies with *specific* implementation strategies. For

instance, there are pros and cons associated with data-warehousing systems in general, but some data warehouse implementations are more effective than others.

Usability

Ease of use is an important technical consideration when evaluating information systems. However, ensuring good usability is a non-trivial task. Developers must take care to adopt user centered design practices that are shown to be effective in maximizing the usability (Baeker et al. 1998, Scheiderman, 1998, Rouse, 1991, Nielson, 2000). The end goal of any tool is to provide an improved method for completing a task, where 'improvement' could be defined in many ways, such as being more efficient, less expensive, having more positive side effects or fewer negative impacts. Good usability removes costs associated with the use of a technology and therefore helps to ensure the diffusion of that technology throughout an environment. The rate at which an innovation diffuses through a user population depends largely on the individual costs associated with using the innovation such that the rate of diffusion increases as costs decrease (Rogers, 1995). Furthermore, the likelihood that users will be able to accomplish specific tasks depends on the quality of the interface design (Ferdinandi, 1999). Systemically, if a tool or information system is difficult to use, only a few end-users will master it, resulting in information flow bottlenecks. Ideally, an educational information system will be accessible by all user groups (not to be confused with allowing access to all data). Finally, since there is a fairly high degree of variation in information needs between user groups, the system should be able to anticipate user needs depending on users' profiles, such that when a teacher logs on, she is presented with options and views that are appropriate to the informational needs teachers in general share.

Software Tools: Client/Server Architecture

One way of differentiating between information tools using technical design as a basis for comparison is to identify how they are designed to interact with a computer network. This distinction arises primarily out of the historical development of information systems. Historically, the only way to make data available to multiple users was to adopt a mainframe architecture where a mainframe houses the data and software that is accessed via dummy terminals (Watterson, 1994). This was the only viable option for many years and many districts still rely on mainframe legacy systems.

The advent of the personal computer in the late 1970's made it possible to distribute the processing demands to the end user and away from the central mainframe. This approach works well until end users, also called *clients*, need to share information or files. Therefore, *client/server* architecture was designed to distribute processing demands while maintaining centralized information management (Heinrich, 1993). This can be a useful way of differentiating between various information tools. For example, tools that are sold as stand alone software packages are not likely to provide strategies for centralized information services. On the other hand, tools that are designed to be accessed through a server or network will require some expertise to install and administer (Watterson, 1994).

Finally, it should be noted that client/server software usually has been designed to operate with certain operating systems. This is usually an issue because many education sites are comprised of

a combination of Windows and Apple platforms. However, the advent of the World Wide Web and the web browser has given rise to platform independent Java and many vendors have developed web-based clients. These clients require unique implementation support at the server end but are able to be used across platforms.

Database Type: Transactional versus Relational

There are two relevant types of databases that should be considered within this section. A transactional, or operational, database is designed to process routine accounting information. Since these systems evolved in corporate world, the systems usually emphasize traditional accounting operations, such as payroll, inventory control, and accounts receivable (Parker, 1998). This requires that transactional systems perform redundant operations in a predefined fashion on up to the minute information. For an organization such as a school district, a transactional database would be an appropriate tool for processing attendance and grade data. Many transactional systems rely heavily on mainframe resources to process and analyze data queries. In contrast to transactional systems, relational databases are different in that they allow developers to define relationships between data elements. Furthermore, these systems are designed to support analysis and reporting, rather than collection and archiving.

System Tools: OLTP versus OLAP

On-line transactional processing (OLTP) describes an information system that is designed to accommodate the flow of transactions (e.g., attendance records, discipline referrals). Data in transactional approaches is stored in data tables that have a prescribed format. In theory, this type of system could accommodate many information needs for a school or district. However, OLTP systems are limited in terms of data retrieval. Namely, extracting large sets of data in an ad hoc way is difficult because the user must be very knowledgeable of the structure of the data tables. Also, transactional systems are designed to store data rather than to retrieve and analyze data. A transactional system will be less able to cope with heavy or increasing demand than a relational database.

On-line analytical process (OLAP) tools, by comparison, are designed to accommodate the collection of data and information that are not necessarily centered around a transaction document. Rather, OLAP tools provide for the multi-dimensional analysis and viewing of large datasets (Ferdinandi, 1999; Barbará, 1997). For example, OLAP tools allow users to view and possibly analyze aggregate data (e.g., semester grades) along a set of dimensions (e.g., grade, school, ethnicity) and hierarchies (e.g., daily and weekly grades). OLAP data are organized into data cubes to represent aggregated (or disaggregated) data elements. This enables users to apply advanced analysis techniques on even very large sets of data (Ferdinandi, 1999; Barbará, 1997).

A *data warehouse* is an example of an OLAP system. A data warehouse is simply a facility designed to store large amounts of information gathered from a variety of sources such as other relational or transactional databases (Parker, 1998). *Data mining* refers to the act of analyzing data stored within data warehouse. Analysis techniques vary; some of which employ traditional reporting techniques such as table and graph generation while others utilize sophisticated pattern

recognition, statistical, or mathematical techniques. A *data mart* occurs when a select group of users are given access to a subset of data within a data warehouse. These users usually have special needs and the data are pre-treated before being made available to users (Ferdinandi, 1999).

Performance

Performance is a key issue with information system design, especially when talking about OLAP solutions. This is true because these systems are designed to be dynamic and, thus, the amount of time it takes a system to process a query and provide the user with acceptable output impacts the usefulness of the system as a dynamic tool (Barbará, 1997). Variables that can be expected to impact performance are: the networking and computational capacity of the computers, the amount of data being analyzed, and the number of users concurrently using the system (Ferdinandi, 1999). Performance delays due to user demands can be compensated for by good implementation practices. However, there are limits associated with some systems, while others require minimal processing and network capacity. Identifying these limits and requirements may help to differentiate between possible information systems or tools.

Storage Requirements

Storage capacity is defined as the amount of data a system can store and process. Information systems vary on how much data can be stored and made available for processing. As noted in the data characteristics section, as grain size decreases and temporal resolution increases, the size of a database will drastically increase. The number of students will also affect the size of a database, as will the number of data elements and attributes that are tracked. In addition to the above demands, as a system is successfully implemented, the technology is diffused among potential users (Rogers, 1984), thereby further increasing demands on the system. Ideally, the system will be scalable as demand increases; for example, data-warehousing solutions provided by Synera (<http://www.syneracorp.com/products.htm>), which EDsmart is based on, has a maximum database size of about 320 petabytes for a 32-bit system. Most likely, performance during analysis processes will be highly dependent on the size of the dataset being analyzed. For example, Quality School Portfolio (CRESST, <http://www.cse/ucla.edu>) suggests that users divide datasets according to cohort to maximize processing time. Noting storage limits or requirements may serve to differentiate between two potential solutions.

Workflow Management Systems

Workflow management systems (WFMS) attempt to streamline and coordinate the process of utilizing data (Mohan, Alonso, Günthör, Kamath, 1995). This is accomplished by representing data processes as *workflows* and reducing these processes to individual activity steps while specifying the necessary order, conditions, dataflow, users, and software tools. WFMS attempts to build a common working environment, which integrates and represents all of the necessary components for a particular workflow process. However, it is the integration of various tools that is the most difficult to accomplish (Mohan et al., 1995). WFMS are still fairly new and are mentioned here because it is expected they will gain prominence as these tools become more advanced.

Summary and Conclusions

Systemic reform efforts, however they are implemented, can be expected to benefit from technological advances in information systems that support the collection and analysis of educational data. This paper has attempted to integrate what is known about how educational professionals use data with what is known about information systems. As a result, we have developed a framework that can be used to analyze or compare various information systems. This framework uses four major dimensions to discriminate between information systems: User Needs, Data Characteristics, Analytic Structures, and Technical Considerations. It is hoped that the four dimensions lay the groundwork for future comparisons of information tools. Furthermore, it is hoped that this work provides readers with a language and common contextual background.

The dimensions described in this paper can be used to compare and contrast information tools. For example, consider a hypothetical situation where a school is considering investing in some technology to help automate record keeping in the classroom. There are several options to consider which range from simple and inexpensive to elaborate and costly. Electronic grade books are an example of simple and inexpensive classroom based information tools. Typically, these tools are designed to replace the paper grade book with an electronic version that records attendance and grades. Many will provide additional features, such as Internet or email integration. Another option is to consider developing or implementing a database application for an entire school. This option will undoubtedly be more complex and probably more expensive, but it will provide school administration with a centralized database. Yet another option involves extending the tool district wide.

In the above example, the question is which of the three strategies is best. Figure 3 is a blob diagram that shows how three hypothetical systems can be compared using two of the dimensions identified in this paper. User needs are represented on the y-axis and analytical structures are resented along the x-axis. Each system's blob represents the degree to which the system encompasses each dimension. In this example, System A would most likely be a school wide database application that has been developed to provide information geared for use by a school administrator. As represented in the figure, this system is designed to report and aggregate data. System B is also designed for district and school administrators, but offers a wider variety of analytical tools. System C on the other hand, is designed for classroom use and focuses on teachers, students and their parents as their intended user groups.

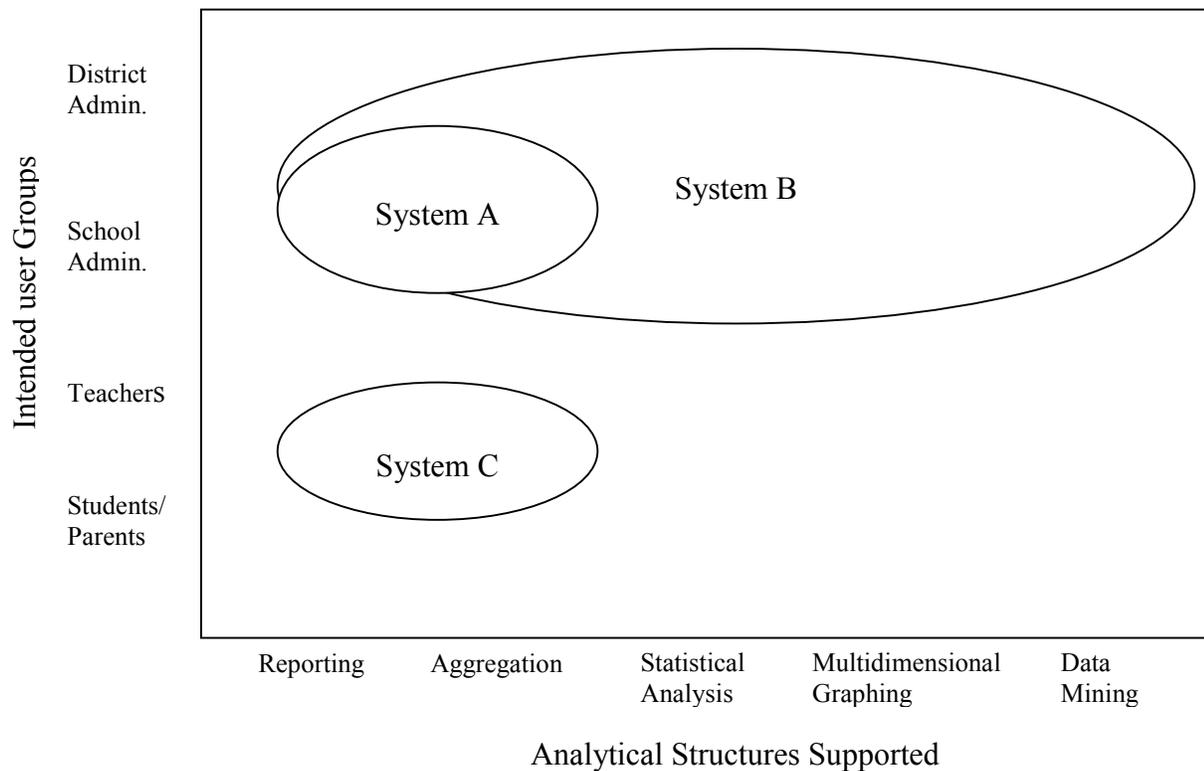


Figure 3. A comparison of hypothetical information tools and systems according to how well they meet user needs and the analytic functions they support.

Depending on the needs of the reader, these dimensions can be combined in different ways to best reveal critical differences between information tools and systems. As seen in the above example, combining user needs with analytical structures will help reveal how tools fit with an organization’s functional needs. In contrast, looking at data characteristics and technical considerations will help identify differences in how tools are implemented. It is in this way that these dimensions create a comparative framework.

Finally, we have also identified the characteristics of a “good” information system. In general, several user characteristics are of importance. Perhaps the most important feature is whether or not the system has been designed to be used by all the different stakeholders within an educational system. Adopting a user-centered design approach will help to maximize the utility of the system, as well as its ease of use (see Chapter 2 in Baecker, Grudin, Buxton, & Greenburg, 1999 for review).

Within a development framework, user-centered design practices can influence each of the four dimensions discussed. User needs can only be accurately assessed with techniques such as interviewing, task analysis, and questionnaires. Furthermore, A good user needs analysis will also determine what information is important to users, as well as how that information is used within the context of the users work environment. This knowledge will impact how the system treats data characteristics such as the metadata schema, temporal resolution, and grain size. A user needs analysis should also inform what analytical structures are important. Are users

interested in conducting statistical analysis or do they just need to be able to create simple comparisons between groups (i.e. calculate and compare means). While technical consideration can not be determined strictly through user needs analysis, understanding who the intended users are will certainly inform many implementation decisions. For example, knowing how many users or what users want to be able to do will inform whether or not a large scale system is needed.

This work should be useful to any organization that is considering implementing or upgrading the way they manage student information. Not only can the dimensions be used as a framework with which to compare and contrast various information strategies and tools, they can also be useful for understanding what an organization needs to consider when implementing a new system.

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Appendix
Condensed Outline of the NCES Data Elements

A. PERSONAL INFORMATION

- Name (12 data elements)
- Background Information (32 data elements)
- Address/Contact Information (22 data elements)
- Family Information (15 data elements)

B. ENROLLMENT

- School Information (20 data elements)
- Entrance Information (10 data elements)
- Tuition and Fee Information (6 data elements)
- Financial Assistance (5 data elements)
- Membership Information (1 data element)
- Attendance Information (6 data elements)
- Exit/Withdrawal Information (12 data elements)*
- Non-Entrance Information (1 data element)

C. SCHOOL PARTICIPATION AND ACTIVITIES

- Session Information (12 data elements)
- Course Information (21 data elements)
- Grading Period Information (3 data elements)
- Performance Information (16 data elements)
- Progress Information (2 data elements)
- Honors Information (5 data elements)
- Activity Information (10 data elements)
- Graduation Information (10 data elements)

D. NON-SCHOOL AND POST-SCHOOL EXPERIENCE

- Non-School Activity Information (8 data elements)
- Institutional/Organizational Information (7 data elements)
- Work Experience (14 data elements)
- Post-School Education/Training (4 data elements)
- Other Post-School Information (4 data elements)

E. ASSESSMENT

- Assessment Information (10 data elements)
- Administrative Issues (10 data elements)
- Score/Results Reporting (9 data elements)

F. TRANSPORTATION

- Transportation Information (4 data elements)
- Transportation Contact (7 data elements)
- Distance/Time Information (3 data elements)
- Vehicle Information (6 data elements)

G. HEALTH CONDITIONS

- Identifiers (8 data elements)
- Oral Health (9 data elements)
- Maternal and Pre-Natal Condition (3 data elements)
- Conditions at Birth (3 data elements)
- Health History (8 data elements)
- Medical Evaluations (16 data elements)
- Disabling Conditions (9 data elements)
- Medical Laboratory Tests (3 data elements)
- Immunizations (4 data elements)
- Nutrition (1 data element)
- Referrals (5 data elements)
- Limitations on School Activities (4 data elements)
- Health Care Provider (13 data elements)
- Other Health Information (8 data elements)

H. SPECIAL PROGRAM PARTICIPATION AND STUDENT SUPPORT SERVICES

- Identification Procedure (14 data elements)
- Early Childhood Program Participation (9 data elements)
- Individualized Education Program Information (4 data elements)
- Special Program and Student Support Service Participation (7 data elements)
- Special Program/Services Delivery (8 data elements)
- Service Provider (1 data element)
- Monitoring Procedure (2 data elements)
- Program Exit (2 data elements)

I. DISCIPLINE

- Nature of Offense (6 data elements)
- Disciplinary Action (7 data elements)

ENTITY LIST

- Student
- Parent/Guardian
- Employer
- Sibling(s) or Other School-Age Children Living in Student's Household
- Responsible Adult of Student's Household
- Other Adult Living in Student's Household
- Sponsor
- Emergency Contact
- School
- Local Administrative Unit (LAU)
- Counselor

Homeroom Monitor

Class

Teacher

Postsecondary Institution

Assessment

Evaluator

Transportation Contact

Transportation Vehicle

Health Evaluation

Health Care Provider

Program/Service

Service Provider

Disciplinarian