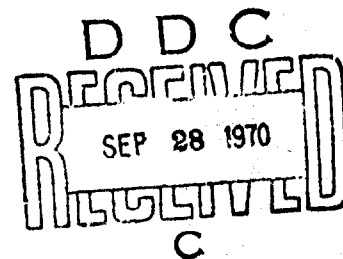EDUCATIONAL INFORMATION SYSTEM DESIGN

A CONCEPTUAL FRAMEWORK

F. W. Blackwell, B. W. Boehm,
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INTRODUCTION

The effectiveness of any educational institution greatly
depends upon information collection and transfer. A variety
of informational "inputs and outputs" are associated with each
facet of the educational process. Many may be classified as
routine, such as attendance and grade reporting; others,
such as parent and teacher expectations, are highly subjective,
yet equally important in judging the benefits of education.
The term *information system* describes the full range of pro-
cesses, methods, and techniques through which educational data
are collected, permuted, and dispersed.

A multiplicity of alternatives confronts the administrator
who considers building a formal information system. The com-
plexity of such a system can range from simple manual records
in classrooms and administrative offices to sophisticated
automated systems serving large metropolitan areas. The ad-
ministrator's needs may best be met by using a remote, already
existing service, such as the California Educational Informa-
tion System. Few "rules" exist for the administrator who has
decided upon an information system as a solution to his prob-
lems; few relationships or measures of effectiveness for various

configurations have been established. Information system
design is primarily an *ad hoc* activity, depending more upon
expertise than on formal methodology.

A number of critical aspects of educational information
system design are discussed below. The success of any in-
formation system depends largely upon several key decisions
that must be made early in the preliminary design phase.
This Paper attempts to (1) indicate the nature and some of
the major implications of these key decisions, and (2) provide
a framework for rational decisionmaking.

THE INFORMATION SYSTEM AND THE OPERATIONAL SYSTEM

An information system cannot be designed in the abstract,
that is, without reference to the particular educational en-
vironment under scrutiny. (For convenience, we call this
environment--the complex of curricula, standards, programs,
and material and human resources--the *operational system*.)
Conversely, some decisions on information-system implementa-
tion will have strong and direct effects on the operational
system. A properly thorough treatment of information-system
alternatives must cover all such interactions with the opera-
tional system. Table 1 shows the relationship among key
information-system and operational-system decisions. The
Paper is organized along the same lines as Table 1, that is,
the section headings roughly parallel the boxes in the table.
This organization conveniently illustrates the interdependence
of pertinent design decisions. All too often, decisions are
made by those responsible for one type of system without
proper consideration of the full implications of the decision
upon other areas. Thus, this table affords the administrator
an indication of points where greatest care must be taken.
In addition, it may serve as a mechanism to judge when "danger
signals" are appearing in the domain of others.

Table 1

RELATIONSHIPS OF KEY INFORMATION SYSTEM AND OPERATIONAL SYSTEM DECISIONS

Decision	Affects Primarily Operational System	Affects Both Information and Operational Systems	Affects Primarily Information System
Operational-System Decisions	***1. Issues concerned with curricula, innovative programs, bureaucratic structure, etc.	***2. Overall time schedule of information system development. ***3. Relative level of expenditure on the information system. ***4. Educational Program Structure. ***5. Administrative structure. ***6. Level of accountability.	**7. Extent to which precautions should be taken to safeguard information privacy. *8. Extent of collection of follow-up data on graduates. *9. Provisions needed for correlations with external sociological data.
Information-System Decisions	**10. Amount of data-collection load to be placed on teachers and students. **11. Extent to which information systems will be used for research.	*.*12. Questions concerning information availability: quantity, level of detail, speed, and accuracy. *13. Extent to which information system should be concentrated at a single center.	***14. Choices of hardware configuration, information request monitoring, and data structure. *15. Whether or not to build a prototype information system.

Two factors somewhat offset the benefits of this approach. First, such questions seldom fit neatly i to any single box: and second, the *relative* importance of the questions is sometimes obscured. In the first case, such assignments are not excessively misleading when viewed with a healthy skepticism. To minimize the second drawback, we indicate the relative importance of the points in Table 1 as follows:

*** Decisions vital to the system's effectiveness.

** Decisions that can strongly affect the system's effectiveness.

* Decisions that can affect several aspects of the system's effectiveness.

This classification of issues is used throughout the Paper.

OPERATIONAL-SYSTEM DECISIONS PRIMARILY AFFECTING THE OPERATIONAL SYSTEM

Issues Concerned with Curricula, Innovative Programs, Bureaucratic Structure, etc. [***]

The form of the information system must reflect the structure and purpose of the educational institution. This category is included as a summation of this point. Further discussion will be found under each of the headings enumerated below, where the various decisions are individually identified and examined.

OPERATIONAL-SYSTEM DECISIONS AFFECTING BOTH INFORMATION- AND OPERATIONAL-SYSTEMS

Overall Time Schedule of Information System Development [***]

Given an important project and strong financial backing for its early phases, a strong temptation often arises to achieve a working operational system as soon as possible.

This frequently leads to a situation in which the schedule
for designing the associated information system heavily
overlaps the schedule for implementing it; for example,
beginning the layout of the data-collection forms before
completing the study of desired processing outputs.

*Unless the information system is strikingly similar
to one that the designers have already implemented, simul-
taneous design and implementation will almost certainly
produce revised specifications that lead to costly, time-
consuming changes in the partially implemented forms of
software.* Well-documented examples of this phenomenon in
educational information systems are difficult to find, but
consider the published experience in another software field:
producing FORTRAN compilers for different computers.[†]

Effort No. (same group)	Estimated Man-months	Actual Man-months
1	36	72
2	24	36
3	12	1́

The successive ratios of actual development time and
of estimation accuracy are fairly typical of information
systems in general, whether or not they are computer-based.[‡]

[†] E. Naur and B. Randell (eds.), *Software Engineering*,
NATO Scientific Affairs Division, Brussels, Belgium,
January 1969, p. 74.

[‡] At first glance, there is little apparent similarity
between sophisticated FORTRAN compilers and applications
programs. However, despite the difference in program
sophistication, the requirements of a FORTRAN compiler are
rigidly defined by two constants (the structure of the
FORTRAN language and the set of machine instructions). An
educational information system has no such boundaries. Thus,
it is much more difficult to define its realm, and to avoid
redefinition during implementation. These considerations
make estimating extremely difficult.

The most severe time limitations arise when one wishes
an information system to monitor an experimental program.
In many cases, there is no time to undertake an orderly
development prior to the start of the program. However,
there are other alternatives besides using an inappropriate
existing information system or delaying experimentation
until the new information system arrives. Perhaps the most
attractive is the temporary use of an existing information
system while a new system is being designed and implemented.
System design could then be based upon the lessons learned
through the (relatively) inexpensive experience with the
pre-existing system. The price is a possible loss in com-
pleteness of longitudinal data. However, this procedure
allows both an early start and orderly development of the
information system, with the added advantage of being based
on actual experience.

Relative Level of Expenditure on the Infoamation System [***]

The appropriate level of expenditure for the information
system is a difficult question, answerable only when the
resources, problems, and requirements of the specific school
are well understood. Obviously, the other points discussed
in Table 1 will directly bear on the cost of the information
system. Information system configuration (and attendant
costs) must reflect many aspects of school operation. In
particular, the amount of experimental and innovative ac-
tivity materially determines the requisite scope and
sophistication of the information system. A properly de-
signed information system can greatly assist in certain
areas of evaluation, as well as be responsive to the day-to-
day needs of the school.

Several particulars on the cost and effectiveness of
information systems deserve special consideration. As seen
in Fig. 1, one buys information-system effectiveness with
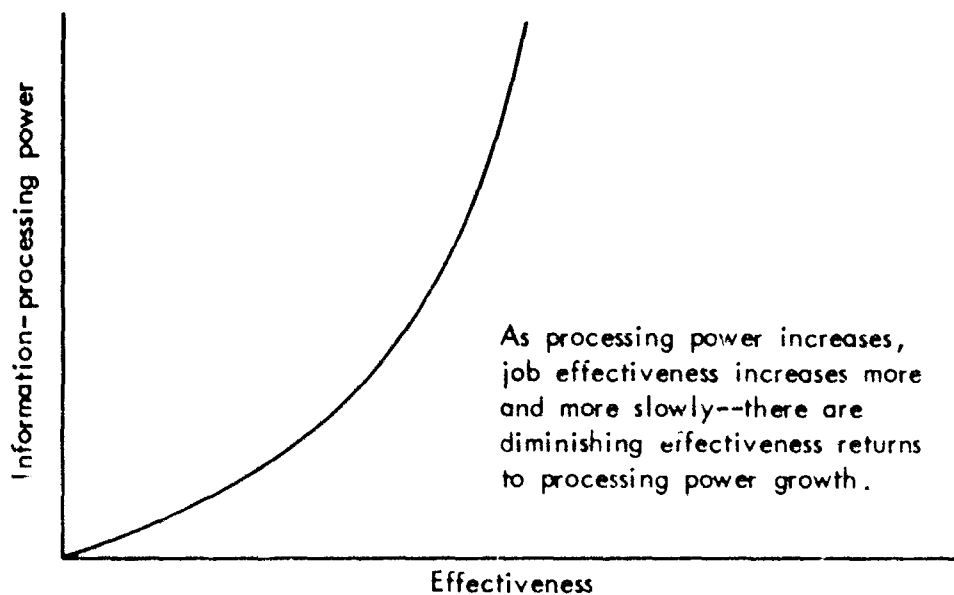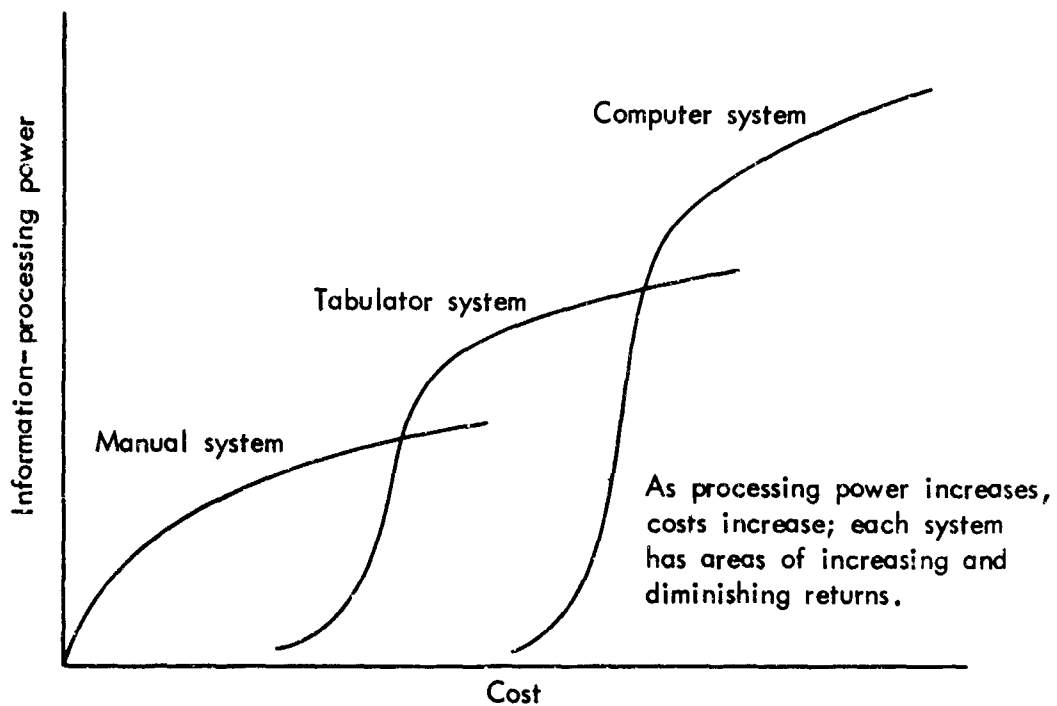information-processing power, i.e., the capability to do a

Fig. 1--Relationships Between Cost and Effectiveness
of Information Systems

certain number of arithmetic and logical operations per
hour. This generally relates to effectiveness in the smooth
manner indicated in the lower (effectiveness) curve. However,
the numerical values along this curve, especially that of
the "point of diminishing returns," are highly dependent
upon the character of programs and routine operations, and
can be determined only after a good deal of analysis.[†] As
the "plateau" characteristic of the set of upper (cost)
curves indicates, a premature decision on a particular type
of information-processing system (manual card-file, punch-
card, and tabulation machines; or a computer-based system)
may commit one to a higher or lower plateau of information-
processing power than is necessary. At that point, re-
designing and converting to the appropriate system can be
expensive in both time and dollars.

Figure 2 shows a fairly typical breakdown and time-
phasing of the expenditure rate for a relatively large
educational information system.[‡] Note that only one-third
of the annual operating cost is allocated for equipment (of
the remaining two-thirds, 44 percent goes for staff salaries
and 22 percent for operating costs), and that staffing levels
for planning and design are comparable to those required
during the operational phase. These figures are comparable
to those reported for information systems in large corporations.[††]

[†]It is important to understand that Fig. 1 is an expres-
sion of broad, imperfectly understood relationships. Any
effort to assign numbers to either axis would require a de-
tailed treatment far beyond the scope of this Paper. This
is particularly true of the effectiveness scale. To our
knowledge, no single effectiveness criterion exists that
allows rational, quantitative comparison of manual, tab, and
computer systems.

[‡]L. E. Yarbrough, "The Florida Plan for a Statewide
Education Management Information System," *J. Assoc. Educa-
tional Data Systems*, September 1969, pp. 1-9.

[††]W. F. Sharp, *The Economics of Computers*, The RAND Cor-
poration, R-463-PR, August 1969. (Also, Columbia University
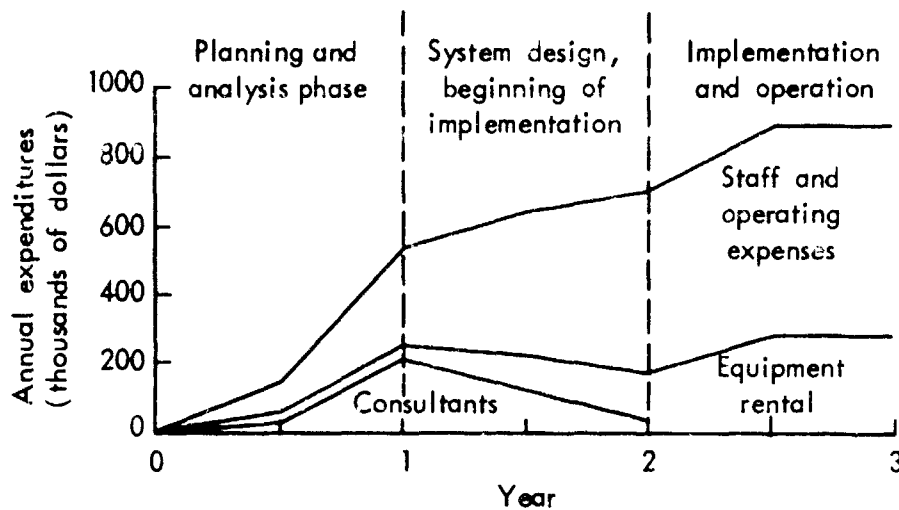Press, New York, 1969.)

Fig. 2--A Sample Phased Budget for an Educational
Information System

Some monthly rental ranges for two typical computer-
based information systems are:[†]

Characteristics	Basic Card System	Basic Card-Tape System
Computer memory, words	4000	8000
Card reader, words/min	800-1000	800-1000
Card punch, words/min	250-300	250-300
Line printer, lines/min	700-1000	700-1000
Tape units	0	4
Monthly rental, dollars	700-1500	1500-5000

Of course, alternative ways of securing computing power
(e.g., service bureaus and time-sharing systems) must also
be evaluated, and other options considered (e.g., using a
computer for both data management and computer-aided
instruction).

[†]Keydata Corporation, *Computer Characteristics Review*,
Vol. 9, No. 2, 1969.

Educational Program Structure [***]

An effective information system design must reflect
the school's educational structure and philosophy. If many
of the educational programs are upgraded, incorporating a
large volume of grade-analytical routines would be wasteful.
On the other hand, such an environment might well demand
that the information system effectively store and retrieve
qualitative and non-numerical information.

Administrative Structure [***]

Similar consideration must be made of the various
possible aggregations. A school organized along "depart-
mental" lines might effectively utilize reports of overall
department activities and achievement, whereas other schools
might prefer primary aggregation of data by grade, or based
upon some criteria of measured ability. The information
system should be designed so that a minimum of manual (or
specially-requested computer) recalculation is necessary
to fit the data to the existing bureaucratic and pedagogic
structures.

A final relevant structural point concerns the *context*
of the institution using the information system. In most
cases, this institution will be required to submit reports
to district, state, and even national authorities. Proper
and insightful system planning can insure that this is done
with a minimum of difficulty; poor planning can insure that
it will be a painful, disruptive, and expensive experience.

Level of Accountability [***]

"Accountability" is a voguish, if somewhat obscure (in
operational implications) concept. It implies measurement
of transactions involved in education: transactions both
of human and material resources, and of learning itself.
An information system can materially aid such a measurement

of the effectiveness of this transaction, and the identifi-
cation of responsibility for it. The *level of accountability*--
classroom, department, administrative--in turn defines several
aspects of the information system (e.g., data collection mech-
anisms, and report structures). In addition, accountability
demands integration of educational and resource data--a
difficult part of system design.

OPERATIONAL-SYSTEM DECISIONS PRIMARILY AFFECTING INFORMATION-SYSTEM PERFORMANCE

Extent to Which Precautions Must be Taken to Safeguard Information Privacy [**]

A large file of organized information on student and
teacher performance, perhaps including socioeconomic data
and indicators of parent and teacher attitudes, presents a
strong temptation for possible abuse for private profit or
unauthorized use by public agencies.

Such safeguards as user passwords and file-protection
programs, if designed into the system from the beginning,
provide adequate security at an incremental information-
system cost of just a few percent (to accommodate the extra
routines, data fields, and validation required). However,
adding the safeguards after system implementation adds from
25 to 50 percent to the information-system cost. Informa-
tion privacy considerations have been discussed in detail
elsewhere.[†]

Extent of Collection of Follow-Up Data on Graduates [*]

This concerns the collection of follow-up data on
graduates of both the educational system and particular pro-
grams. The root of the problem is that geographical distri-
bution expands as time increases. There is no easy solution;

[†]W. H. Ware, *Security and Privacy in Computer Systems*,
The RAND Corporation, P-3544, April 1967.

the problem is mentioned here simply to indicate that the
school in question should consider some commonality of
system design, or at least lines of effective communication.
This consideration is particularly appropriate within the
State of California, where the California Educational In-
formation System (CEIS) provides some measure of consistency.

Provisions Needed for Correlations with External Sociological Data [*]

If the implications of performing correlations--resolving
differences between boundaries of school districts and census
tracts, determining comparable data accuracy, providing cross-
references between files--are thought through in advance, and
the information system structured with respect to these con-
siderations, then the job will be relatively straightforward.
However, it may be quite difficult to provide for such cor-
relations after the information system has been implemented.

INFORMATION-SYSTEM DECISIONS PRIMARILY AFFECTING OPERATIONAL-SYSTEM PERFORMANCE

Amount of Data-Collection Load to be Placed on Teachers and Students [**]

In implementing an information system, decisions could
be made on data collection that might seriously impair
teacher or student performance. For example, in an experi-
mental situation, having the teacher monitor and record the
class attention level during a programmed instruction se-
quence both reduces teaching effectiveness and makes the
class atypical with respect to normal teacher performance.

Extent to Which Information System Will Be Used for Research [**]

A well-designed information system should be quite
useful to a broad spectrum of potential "clients": teachers,

counselors, school and district administrators, parents.
Furthermore, extending the information system could signi-
ficantly increase its utility in the performance of research.
The concept of such a "multipurpose-multiuser" information
system has been explored in some detail by Coleman and
Karweit and holds considerable promise for improving the
effectiveness of the school system.[†] The cost of such
efforts should be carefully evaluated. Design of an infor-
mation system that would be "all things to all men" is
probably not possible. In any event, the attempt would re-
quire massive expenditure. In that all research requires
different data, the tradeoffs between flexibility, compre-
hensiveness, and cost must be carefully examined.

INFORMATION-SYSTEM DECISIONS AFFECTING BOTH INFORMATION-
AND OPERATIONAL-SYSTEMS

Questions Concerning Information Availability: Quantity,
Level of Detail, Speed, and Accuracy [***]

Questions concerning the speed, accuracy, and quantity
of information that should be made available for requests
are fundamental to the design of the information system;
their answers determine the goals of the hardware-software
design process (see p. 15 below). Formulating the answers
requires close collaboration between information recipients
and information-system designers. However, a further key
decision must be made on the extent to which the information
system will support educational research along the "multi-
purpose-multiuser" lines envisioned by Coleman and Karweit.

These considerations provide the guidelines for the ex-
tent, level of detail, and retrievability of the information

[†] J. S. Coleman and N. L. Karweit, *Multi-Level Informa-
tion Systems in Education*, The RAND Corporation, P-4377,
June 1970.

stored in the data base. For example, decisions must be
made on the level of detail of test scores to store for a
variety of tests. Is the overall score on the test suf-
ficient for research purposes, or should performance on
individual questions or groups of questions be recorded?
Is right/wrong a sufficient indicator of performance in
answering a question, or is more detail needed? Similarly,
in keeping records on supplementary help for students by
parents or tutors, decisions must be made about the ways to
indicate frequency of help, length of session, type of help
(reading, drill, playing "store," or word games), and per-
haps about ways to classify attitudes and their evolution.
Furthermore, the relation of educational costs to effective-
ness will require new breakdowns of traditional accounting
information.

The way these questions are decided in turn determines
the information system's cost and effectiveness. But the
people making these decisions are generally quite external
to the policymaking structure. If their individual efforts
are to result in a consistent, efficient, and useful in-
formation system, they must be provided with well-defined
guidelines concerning information privacy, the use of
sociological data, the data-collection load, and other
factors.

Extent to Which Information System Should be Concentrated at a Single Center [*]

Centralized information-processing operations decrease
duplication of effort and allow more economies of scale in
equipment and personnel. It is also much easier to identify
information-processing costs and relate them to information-
processing effectiveness in a centralized operation. If
the organization considering implementation is a school dis-
trict, county, or state, much can be said for the benefits
of centralization.

On the other hand, a more decentralized information system would generally respond more rapidly to school administrators and teaching personnel, and would also provide more local checks on the accuracy and consistency of data. A central-computer, remote-terminal system could provide some of the advantages of both centralized and decentralized operations.

INFORMATION-SYSTEM DECISIONS PRIMARILY AFFECTING INFORMATION-SYSTEM PERFORMANCE

Choices of Hardware, Information Request Monitoring, and Data Structures [***]

The information system will have a number of basic tasks to perform, including:

o Entering standard types of data into the system.
o Entering new types of data into the system.
o Formatting, abbreviating, and coding of data.
o Producing standard reports.
o Producing new types of reports (previously unanticipated).
o Answering specific, one-time requests.
o Processing information (e.g., sorting and correlating).
o Reacting to various errors.
o Relating to other information systems.

How well the system does these jobs, and the cost it incurs, depend 1) on the choices made on the nature of the hardware and software components, and 2) on the division between manual and computer operations. For example, choosing the number of "keys" by which information is stored produces different levels of retrieval efficiency, storage costs, and flexibility. Library books are usually catalogued with three keys: author, title, and subject.

In a school system, student records maintained manually may
be keyed only by name. A question such as "What students
live in non-English-speaking homes?" usually requires a
search through the entire file (if that information is
present), even though the number of such students is prob-
ably small. A computer is able both to search the whole
file quickly, and to organize it in many ways to allow
direct retrieval of information without expensive searches.

The computer is particularly valuable in complex pro-
cessing of filed information. "How do students' grades
correlate from one year to the next?" is a reasonable ques-
tion for a computer information system, an unreasonable
one for a manual system. A convenient, natural way (a
special "inquiry language") of expressing such requests to
the computer is helpful.

Whether or Not to Build a Prototype Information System [*]

Building a prototype is a tactic available to informa-
tion-system designers facing a relatively new and undefined
task. A prototype allows experimentation with facets of
the information-system design, without all the inertias of
a full operating system. However, it requires that extra
time be allocated for project definition.

*   *   *   *

It is important to reiterate the *sequential* nature of
1) establishing information-system policies, 2) determining
the accuracy, volume, and retrievability of the information
to be maintained, and 3) designing and implementing the
hardware-software system. As emphasized in the decision
on overall time-phasing (see p. 4), an attempt to squeeze
these three phases into one concurrent process usually re-
sults in a loss rather than a gain of elapsed time.

It is equally important to stress the necessity for iteration and feedback between teachers, students, administrators, research teams, and the information-system designers. Unless mechanisms exist for representatives of each of these groups to contribute to the decisionmaking processes of the other groups, the information system will lose effectiveness, and take even longer to develop.