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ABSTRACT

Previous work assessing the effectiveness of computers in education has gone no further than acknowledging a network of interconnected variables (comprising a system) which contribute to computer impact and describing its component parts. An impact systems model developed by Glasman and Bibiaminov (1981) has been adapted to facilitate measurement of change in a school's outcomes. This model examines cognitive and affective changes brought about by change in a school's inputs, including student background, school conditions, teacher characteristics, instructional integration of computer use, student attitudes, type of computer use, and hardware and software characteristics. Application of the model to the improvement of computer impact involves examining variables from the perspectives of manipulability and critical upper and lower bounds, which involves the determination of which variables are most important to the successful functioning of the overall system. The model can guide strategy for the improvement of computer impact in schools. The final level of consideration for decision makers relates to identifying effective mechanisms for manipulating critical variables toward "upper bound" characteristics, where particular variables are powerful enough to make the system likely to be successful regardless of other variables. Three possible intervention approaches are increased funding, changes in national or regional policy, and changes in teacher training or retraining. (GL)

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Manipulating Critical Variables:

A Framework for Improving the Impact of Computers in the School Environment

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Paper prepared for EURIT '88, Lausanne, Switzerland, July, 1988.

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**Manipulating Critical Variables:
A Framework for Improving the Impact of Computers in the
School Environment**

**I. What Do We Know About the Effectiveness of Computer-Related
Technology in the School Environment?**

We who work in the area of computer-related technology for educational purposes are frequently asked the general questions: "Where are we now? What do we know about computers and computer-related technology in the school setting? What works?" These are valid and reasonable questions. We as a community have invested considerable money and human resources into the investigation of computer applications in education. Both those who fund us and the constituencies whom we serve are warranted in asking these questions, especially since work in this area has been going on for a considerable length of time--at least since the 1960s. Researchers may argue that the task of enhancing learning with computer technology is so complex that much more time is needed before the field can be expected to offer any response to general questions such as, "What works?" (see, for example, Dede, 1986 for a review of current progress in "intelligent" computer-aided instruction). However, those who must, now, make purchasing, planning, or policy decisions, those who must now organize the next year's teacher training or inservice, cannot afford to wait until researchers work out convincing methodology and summations.. Decisions regarding implementation and reflecting expectations about the impact of computer use are being made daily in the field, regardless of the measured conclusions of the research community. In most cases, expenditure and enthusiasm continue despite the lack of convincing evidence that particular computer applications can transcend the complexity of the teaching/learning process and be expected to "work" in particular schools or area.

However, we cannot expect to be unaccountable, even if now enthusiasm for computers seem to be fueled by its own momentum. Eventually if we are "unable to demonstrate adequately any productivity increase" associated with computer use in education, a consequence may be that "the tightness and shrinking of educational budgets in most countries, developing and less-developed, may rapidly kill these innovations" (Orivel, 1988). In order to maintain the credibility of our conviction that computers can offer distinct benefits in the school setting it is important that we make a response now, albeit an imperfect one, to the reasonable questions, "What do we know? What works?"

II. How Might We Respond to "What Do We Know?"

Certainly we do try to respond to these questions and we

tend to do so in a number of predictable ways. Becker (1988) identifies four typical approaches: 1) broad surveys, 2) observations of individual situations, 3) jurisdiction-wide evaluations with no controls, or 4) conclusions based on experimental activity but conducted over a brief time span and sometimes in unnatural settings. In addition to Becker's categories, other typical responses may refer to areas of current interest presumed to be able to make an impact on learning, or to inconclusive aspects of previous computer implementation, or to the complexity of the task in trying to respond to the basic questions. Let us look more systematically at these response clusters before we advocate a different framework for responding to "What works?" and for decision making based on this framework.

1. Responses based on personal experience

This type of response to "What works?" is most common, and most suspect. Although helpful and generalizable analyses can be made from personal experience, as for example, those based on well executed case study methodology (for an example, see Hativa, 1988b), most responses based on personal experience are little more than anecdotal reports, replete with threats to internal and external validity because of the idiosyncrasies of the particular context and implementation (Clark, 1985a, 1985b).

2. Responses based on survey data over large samples

Another popular response to questions about computer impact in schools is to refer to data from large-scale surveys. Becker, in the US, (1983, 1987b) has contributed widely cited data using this approach. Survey data in turn describe trends from at least four different perspectives.

2.1 Trends in usage, by content area or type of application. National studies in Canada (Collis Kass, Kieren, & Woods, 1988) and the U.S. (Martinez & Mead, 1988) show that usage focussed on teaching about computers or about some specific type of computer usage such as word processing has become widespread in North America. However, usage focussed on augmenting learning of curriculum-related objectives in "mainstream" subjects such as mathematics or science is still "relatively rare" (Walker, 1988).

As an example, less than 10 percent of a sample of 3000 Canadian Grade 11 students representing major urban areas in all Canadian provinces had ever, even once, used a computer as part of their science or "social studies" classes, less than 15 percent in their English (or French) classes, and less than 20 percent in their mathematics classes despite universal availability of computers in secondary schools (Collis, Kass, Kieren, & Woods, 1988).

2.2 Trends in usage, by specialist groups. Survey data often attempt to describe usage by particular groups of students, most frequently gender groups, or groups defined by some sort of learning difficulty. The Canadian and American surveys described in the last paragraph also document the tendency of significantly more adolescent males than females to make use of available school computers. Working from a different perspective, Russell (1987) is one of a number of researchers who have investigated the extent of usage of various computer applications by special education practitioners throughout the United States.

2.3 Trends related to hardware. A number of surveys focus on the typical types and configurations of hardware in the school setting. These show a consistent escalation in quantity of computers in North America schools (see for example, Becker, 1983, 1987b; or Gleason, 1987). Gleason's figures are typical: the student/computer ratio in his jurisdiction (the state of Wisconsin in the US) dropped from 1:155 in 1985 to 1:19 in 1987. Configuration patterns, particularly computer laboratories, whether networked or not, are also described and analyzed in surveys (for example, see Martin & Preskill, 1987). The results tend to show that laboratories are well established, at least in secondary schools, but are not without technical, pedagogical, and organizational problems.

2.4 Trends related to other characteristics of users. Other survey focuses include age or regional data (Martinez & Mead, 1988), data related to socioeconomic levels (Martinez & Mead), and teacher characteristics (Becker 1987b; Ellis & Kuerbis, 1985), among many topics. These data often describe inequities in access related to demographic characteristics (Collis, 1985; Lockheed, 1985).

While survey data are interesting and often can be used by decision makers in other jurisdictions, they most often have little direct relevance to the basic question, "What works?" because of their preoccupation with documenting superficial aspects of what is happening. Because a certain trend occurs does not support its essential relevance or its influence on improved learning.

3. Responses based on predicted impact

Answering "What do we know?" by predicting what could or should occur, based on emerging technologies or futurist perspectives is not uncommon. Currently at least three types of computer-related activities are predicted to have significant potential impact on education. These are telecommunications, data base manipulation, and CD-ROM and laser disk storage (Collis, 1988b). Telecommunications are claimed to have the potential to alter communication styles (Murray, 1985) and to

expand the "walls" of the classroom (Cohen & Mijake, 198 ; Keenan, 1985) both geographically and experientially. However, despite considerable activity in literally hundreds of educational telecommunications projects throughout the world, there is no consistent evidence to support their feasibility in the regular classroom or educational effectiveness, even in the research setting. If consensus is emerging from this experience base, it is most clearly related to the technical and practical problems being encountered at most sites.

Sometimes responses to "What works?" are based solely on the observations emerging from research centers who report promising results with a particular computer-based application in their own pilot studies and laboratory projects. Logo began in this manner (and "success" with Logo is still very likely to come from such atypical and confounded installations [Kieren, 1984]). The most promising new application emerging from this sort of well funded research activity is that of MBLs, or microcomputer-based science laboratories for children, where computers are augmented with data capturing peripherals and appropriate software for instantaneous data display and manipulation. So far, results from these investigations are promising, and suggest a real potential for impact in science instruction (Linn, 1987; Stein, Nachmias, & Friedler, 1988). However, there has been little or no diffusion of the MBL techniques into "regular," non-project supported classrooms, despite easily available software kits and extensive writing and discussion by the MBL community.

4. Responses based on topics of declining interest

Another way to respond to the question, "What works?" is to indicate areas of previous activity in computer applications in education which were once heralded as having much potential impact, but no longer generate much interest, either theoretically or practically. Perhaps the two most prominent examples of this type of declining interest are programming and authoring systems for teachers. During the early 1980s programming was vigorously championed as a valuable learning experience for students of a wide range of ages (Luehrmann, 1981; Papert, 1980). Sometimes the rationale for the advocacy was in the context of developing the students' computer awareness or computer literacy; other times the rationale was the supposed transfer of problem solving skills and higher-order thinking acquired or strengthened through the programming experience to other learning tasks. Despite the strong theoretical arguments to support this sort of transfer (most notably and perhaps most eloquently from the Logo community) and considerable research activity attempting to support this transfer, "the speculated link between the teaching/learning of programming languages and the improvement of problem solving skills has not produced much supporting evidence" (Palumbo & Reed, 1987). This may be to a

certain extent a function of design problems confounding much of this research (for example, Johanson [1988] identifies various hypotheses about these flaws, and Palumbo and Reed document six major design flaws reoccurring in typical studies) or because most school-based programming experiences are not of high enough cognitive challenge to expect problem solving to even occur, let alone transfer (Mandinach & Linn, 1987). Also, computer competency is now seen to be more appropriately based in experience with applications software rather than in programming (Lockheed & Mandinach, 1986). The lack of practical support for programming probably explains the current decline in advocacy of programming in the school setting (other than in computer science classes at the senior secondary level, and even there there is controversy about the appropriateness of programming experiences.)

Another activity which was frequently promoted as having a potential impact on education was the use of authoring packages by teachers so that they could "easily" create their own personalized courseware for their students. This task has not proved to be easy or even feasible, either for time or skill-related reasons or because of technical constraints inherent in most authoring packages. Although Hypercard is currently fueling some resurgence of interest in teacher-generated materials, there is no real expectation that practitioners will be generators of meaningful software.

5. Responses elaborating inconsistent or inconclusive support

Another way to respond to the question, "What works?" is to expand on what we do NOT know, if we base our conclusions on available research.

5.1 Inconclusive support for impact on learning. There is a disappointing acknowledgement among many of the researchers who attempt to synthesize research regarding the impact of computer-related applications on teaching and learning that the impact is not, as yet, what was expected (Becker, 1987a). Clark (1985a, 1985b), for example, reanalyzed the results previously synthesized in various well known North American meta-analyses of studies involving computer-assisted instruction and concludes that teacher effects and instructional method effects appear to be large contributors to most of the significant results that are reported favouring CAI over traditional instruction. Ely and Plomp (1986) comment that, "in surveying the current scene we do not see evidence of a significant, revolutionary use of the various communication technologies" (p. 232). Orivel (1988) discusses the "tons of evaluation literature, poor and good, that has been produced" relative to within-school applications of new educational technologies and concludes that "most are inconclusive on the effectiveness of such programs" (p. 45). Clark, (1983), as well

as Ely and Plomp, note this disappointing lack of solid validation support pertains not only to computer-related technologies but to a variety of educational media. Clark, for example, "reconsiders" the research on learning from media, and states that "consistent evidence is found for the generalization that there are no learning benefits to be gained from employing any specific medium to deliver instruction" (p. 445).

5.2 Design inconsistencies in assessing the impact of word processing. Perhaps the area where consensus is most strong about the benefit of a specific computer use relates to word processing and the writing process (Daiute, 1985). Yet even here the research results are frustratingly mixed, as are the situations generating the results. Hawisher (1986) for example reviews 24 studies and notes the wide range of conditions, outcome variables, and outcomes that are reported. The only consistent result is that word processing users tend to like writing more with a word processor than without one. Daiute (1986) has done particularly helpful work in this area. She notes in one study for example that there was no difference between word-processed text and paper-and-pencil text with regard to the incidence of 22 of 25 common errors in writing, and that, rather surprisingly, writers recopying a text by hand tend to make more internal expansions to the material than do word processing users, who tend to add details to the end of a text rather than within it.

5.3 Complexities involved in computer impact on motivation. Sutton (1987) reviews motivation more generally with respect to classroom computer use. He points out that motivation as an outcome cannot be considered a simple function of computer use, but is very much affected by a variety of factors, such as classroom context, the way the teacher employs computers, and the social organization--cooperative, competitive, or individualistic--around which the teacher structures computer use.

6. "What Do We Know?" revisited: Consensus on complexity

However, out of all the recent research there is one conclusion which is emerging again and again and which IS something we can respond when we are asked "What do we know?" Sutton's research on motivation gives an example of it, as does Hawisher's review of word processing and Johanson's review of programming and its cognitive consequences. This conclusion is that computer impact cannot be summarized in any simple statement because it is inextricably embedded in and covarying with a large number of other variables. An editorial in the Phi Delta Kappan journal (1987) notes, "it is time to stop asking whether CAI 'works'...We would do better to ask, "Under what conditions should we expect transfer of skills and to what other situations might they transfer?"

Collis, Walker, and Grant (1987) identify unavoidable confounding in any computer use situation because of, at least, teacher characteristics; instructional decisions surrounding the computer use; school, class, and class environment characteristics; student-specific characteristics; and software and hardware characteristics. Hawkins and Sheingold (1986) note that technological innovations "are interpreted and shaped by the knowledge, experience, and setting of those teachers and students who encounter them" (p. 43). Pea and Sheingold express this complexity rather gracefully when they say, "educational technologies serve as mirrors of minds and the cultures in which they 'live'...They reflect the expectancies represented in classrooms and the knowledge and skills of individuals using them" (p. x). This is in the same spirit as Walker's (1986) observation that "it is the people and the institutions they create and sustain who determine the success or failure of an innovation. And even when an innovation meets people's expressed needs, it may still not succeed unless it fits in with the patterns by which they run their lives as students and teachers" (p.5).

So, we do have an answer when people ask us, "What do we know?" but the answer is not the one people want to hear because it raises more questions than it resolves. What we know most clearly about the impact of computers in education is that this impact depends on many other things. We know we are dealing with a network of interconnected variables, where an alteration in any one of them can affect the entire system (Educational Technology Center, 1988, Kass, Kieren, Collis, & Therrien, 1987; Viske, et al., 1988). This systems conception is not new in education; it has been developed, among other focuses, for reading research (Lipson & Wixson, 1986), for school effectiveness research (Glasman & Biniaminov, 1981; Stoel & Scheerens, 1988; Webster & Olson, 1988), and educational technology in general (Ely & Plomp, 1986). What is relatively undeveloped, however, is what to do with this systems approach other than acknowledge it and describe its component parts. The remainder of this paper will develop an integrated systems model for computer impact in the school in order to hypothesize some causal aspects of the model and to suggest an approach to using the model for improving the impact of computers in the school environment.

III. A Computer Use Impact Model

Glasman and Biniaminov (1981), in their analysis of "input" and "outputs" of schools, synthesized 33 studies that attempt to measure change in a school's outcomes brought about or at least influenced by changes in the school's inputs. In each study, the school was seen as a system. Their synthesis of these studies produced a structural causal model with five input clusters (p. 536):

- a. Student background characteristics
- b. School conditions (such as services and expenditures)
- c. School-related student characteristics (such as sociodemography of student population)
- d. Instructional personnel
- e. Student attitudes

Output was defined as involving both cognitive and affective aspects. This model was then used to hypothesize main and secondary (or indirect) effects. Among their hypotheses was that teacher characteristics and student attitudes influenced outcomes most directly and strongly compared to the other variable clusters. This model can be used as a framework for "input-output" research syntheses in other educational contexts, including the impact of computers in the school setting.

In order to use this model to represent outputs associated with computer use in schools, it must be adapted; clusters must be added and existing clusters must be redefined, based on the research specific to computer use in education. Appropriate clusters for such an adaptation could be defined and defended as follows:

1. Individual student background characteristics

- Family socioeconomic and educational levels
- Presence of a home computer
- Student's aptitude
- Student's prior experiences and understandings
- Student's preferred learning style
- Student's gender

Collis, Kass, and Kieren (1988) have shown the positive relation between family educational level, home computer availability, and likelihood of using a school computer--for males. Their work, and that of many others, shows gender to be strongly associated with response to and engagement with school computers. Research done at the Educational Technology Center (1988) at Harvard University reinforces the findings of many that students' prior conceptions or understandings about subject matter or computer use affect their response to such use and therefore its impact. Hativa (1988a) has carefully documented the differential impact of computer use on children of different ability levels. She notes, for example, that low ability children using a mathematics drill program make softwares- and hardware-related errors that higher ability children do not make. She also notes that "there will always be students who benefit from some particular type of [computer] work, while other students, with different aptitudes and styles of learning, will face problems working in that particular mode" (p.18).

2. School conditions

- Characteristics of support for computer use
- Appropriateness of inservice opportunities
- Administrative encouragement of computer use

Cox, Rhodes, and Hall (1988) and Collis (1988c) are among many who note the need teachers have for extra preparation time and for other aspects of in-school support in order to make effective (or indeed, any) use of school computer opportunities. Cox and her colleagues also document the importance of the headmaster, or principal, in nurturing computer impact in the school. Cuban (1985) notes the impact the school environment and the "culture of teaching" have on subsequent computer impact. He comments that "settings have plans for their inhabitants" which "situationally constrain choice" for both teachers and students with respect to computer use. Many researchers have noted the critical importance of appropriate inservice and modelling for teachers in terms of what they eventually do with computers in their classrooms. The "levels of concern" model (Hall, Loucks, Rutherford, & Newlove, 1975; Mitchell, 1988) provides useful insights into a framework for planning inservice for the teacher based on his level, both qualitative and quantitative, of experience with an innovation such as computer use in the classroom. Broyles and Tillman (1985) show that mismatches between inservice orientation and teacher's level of concern can result in unproductive and even stress-elevating situations with negative consequences for subsequent implementation decisions on the part of the teacher. Wiske and his colleagues (1988), in a nationwide study sponsored by the Office of Technology Assessment of the US Congress, note that a school support environment that fosters teachers' professional growth and development in computer applications is a necessary (but not sufficient) condition for general staff engagement in effective computer use.

3. Personal Teacher Characteristics

- Teacher's intellectual level
- Teacher's subject matter knowledge
- Teacher's acceptance of computer use
- Teacher's expertise in computer applications in the classroom
- Teacher's attitudes and self-confidence
- Teacher's preferred instructional style

There is an abundance of evidence that the teacher is a critical variable in the impact of any educational tool, including computers (see, for example, Begle, 1979; Brophy, 1986). Levin, Leitner, and Meister (1986) found "profound" differences in the impact of a very structured computer-delivered drill and practice system when this system was monitored by

different teachers, even though the system (Suppes' CCC Curriculum) appears to be virtually teacher-independent. Researchers at the Educational Technology Center (1988) note the inevitable impact of the teacher's "intellectual agenda" on computer impact and "vehemently contradict the popular notion that computer-based lessons can be self-implementing...teachers need a clear understanding of the purposes of the [computer] materials, an image of how to manage teaching in a new way, and a detailed map of the subject matter they have to teach" (p. 20) with (or without) computers. Berger (1986) documents the impact of science teachers' misconceptions and "thinconceptions" on their subsequent use of computers to augment laboratory investigations. As noted before, the teacher's "level of concern", or experience with computer use in the classroom, critically affects his response to inservice offerings in the school; it also predicts his effectiveness in using computers with his students. The teacher's attitude toward computers, toward the use of computers in his lesson, and toward himself as a computer user all affect the impact or even existence of computer experiences for his students (Cox, Rhodes, & Hall, 1988; Friend, 1985). Orivel (1988) notes, for example, that the "high death rate of within-school media [computer] projects is often due to teacher rejection" (p. 46). Teacher's preferred instructional style is also a critical variable affecting computer use. Cuban (1985) and Wiske and his colleagues note that teachers are unlikely to change their characteristic teaching practices when considering computer use, and indeed, "most teachers report no change in teaching style (after starting to use a computer); most adapt computer use to their existing style" (Wiske, et al., 1988).

4. Instructional integration of computer use

- Curriculum relevance
- Lesson integration
- Teacher guidance and feedback
- Organization of student usage

Personnel at the Educational Technology Center at Harvard (1988), among many others, have noted the critical importance, relative to eventual impact, of how the teacher integrates computer use into a lesson or teaching unit. In trying to assist teachers with this integration, they are developing "infusable" support materials for teachers. In addition to curricular and lesson relevance, the ongoing decisions teachers make regarding feedback and suggestions to their students as the students use computers also affect the impact of the computer use on the learners. For example, Carver and Klahr (1987) note that explicit teaching should accompany students' computer "explorations" in order for effective impact to occur. Cox, Rhodes, and Hall (1988) observe that teachers frequently have a "lack of knowledge of how or when to join in children's

microcomputer activities" (p. 176) and thus children fail to learn, or "discover," what they might with judicious teacher intervention. The social organization surrounding students' computer use--if they are guided to work in pairs or groups, cooperatively or competitively--also impacts on student learning (Sutton, 1987; Webb & Lewis, 1987). Webb's work in a variety of studies supports the value of students working in groups at the computer for programming (Webb, 198). Mehan, Miller-Souviney, and Riel (1984) note a similar benefit for writing in a social setting. They feel that "it is not the computer per se that is responsible for improved writing," but that the computer can be the catalyst for an environment that "makes a new social organization for reading and writing possible." In their opinion, "it is the social organization and not the computer alone that has positive effects on the reading and writing process."

In general, then, the teacher is a critical variable in computer impact, both through his personal characteristics and his instructional decisions. "One can theorize with the best of intentions how teaching and school learning could be optimized, but the finest ideas and proposals must still pass through the funnel of teacher planning" (Clark, 1986).

5. Student attitudes

- Student's interest in computers
- Student's self-confidence about computer use

Similar to the evidence about student attitude in Glasman and Biniaminov's study, there is also evidence in the area of computer impact in education that student attitudes have a direct effect on the outcomes associated with computer use in the classroom. Student attitude and self-efficacy have particular impact on the "effort [the students] will invest" in computer use (Salomon, 1981). However, attitude seems so strongly mediated by other factors already defined in our model (such as gender, prior or home experience with computers, teacher expectations of student competency, teacher behaviours, etc.) that it must be considered a mediated effect, not one which exists independently of others in the model. Self-confidence about oneself as a computer user, for example, is strongly related to gender, in fact, so strongly that the gender effect for females can mask the effect of prior computer experiences on subsequent participation (Kass, Kieren, Collis, & Therrien, 1987).

6. Type of computer use

- Drill, tutorials
- Simulations
- Open-ended tools
- Programming

This dimension was certainly not part of Glasman and Biniaminov's model but is critical to ours. There are many ways to categorize type of computer use; the four above reflect an underlying continuum of self-containedness of this use. This continuum could also be described as one of content specificity. The importance of teacher interaction occurs with all types of computer use (note Levin, Leitner, and Meister's 1986 study of variations in cost effectiveness of the same computer drill material used by different teachers in different schools) but accelerates as the type of usage becomes more open-ended.

In addition, the type of computer use can have different impacts on different types of users, especially so with "learner-centered" software (Russell, 1987) where the child is meant to assume control of various decisions within the use of the computer application. Student characteristics also mediate the effect of different types of computer use; Rowland and Stuessy (1987), for example, are among a number of researchers who have shown tutorials to be more effective than simulations for certain types of students (those with a serialist as opposed to holistic orientation, those with external rather than internal locus of control, and those with relatively lower memory skills). This sort of study, however, becomes difficult to interpret unless we know more about the instructional context of the use of the software and about the intervening teacher effect. In general, these same problems of situation confounding are likely to obscure interpretation of research comparing types of computer use, especially those in the "Logo versus BASIC" category, although some studies are available that do a reasonable job in controlling confounding factors in order to isolate a computer-use effect. Two examples are Martin, Shirley, and McGinnis' (1987) study of simulation versus non-simulation experiences and their transfer to achievement in ecology units for fifth- and sixth-graders, and Stein, Nachmias, and Friedler's (1986) investigation of science laboratory experiences for eighth graders with and without computer data capturing (MBL) support and the impact of this type of computer use on set-up time, off-task behaviour, quality of graphic displays of results, ability to draw valid conclusions from data, and student attitudes.

7. Software characteristics

- Choice of wording, contents
- User interface characteristics
- User control of movement through software

There have been many studies on the impact of various aspects of software design on student learning. Gillingham (1988) reviews a subset of over twenty of them, relating to length of text presented at one time, user control or program control of text presentation, scrolling and timing of text

presentation, colour and presentation of text on the screen, and impact of text structure. He notes particularly the importance of "considerate text," where the user's metacognitive monitoring is made easier by text which is adequately structured, coherent, unified, and information-appropriate. Many other studies have identified the impact of specific design decisions on student learning or motivation. Ross and Anand (1987), for example, note that inserting students' names and student-supplied names of people and places into sixth-graders' computer-delivered mathematics word problems was advantageous for both achievement and attitude compared to the use of the same software with pre-set names in the problems. Land (1988) investigated the impact of scrolling of text in tutorial software and found it more effective with "low clarity" presentations than with well explained, or "high clarity" presentations; this study and others suggest that scrolling can help compensate for "inconsiderate text" but may even can interfere with the processing of "considerate text," especially for able students. Hativa (1988b) provides very useful comments on characteristics of drill software that appear to "hinder achievement" compared to pencil-and-paper practice of the same arithmetic drill material.

Clearly, some of the software issues identified by these researchers are mainly pertinent to convergent, fixed-content software rather than to open-ended, tool-type software. However, software characteristics remain important regardless of the level of open-endedness (Wiske, et al., 1988); Ely and Plomp (1986) comment that, "rarely is there any type of educational technology project that has sufficient amounts of quality software, probably the most important element of the total delivery system" (p. 243). Although some would argue the final clause of this statement, there is consensus that software characteristics, particularly user interface aspects, have a critical impact on the effect of computer use in the educational setting.

8. Hardware characteristics

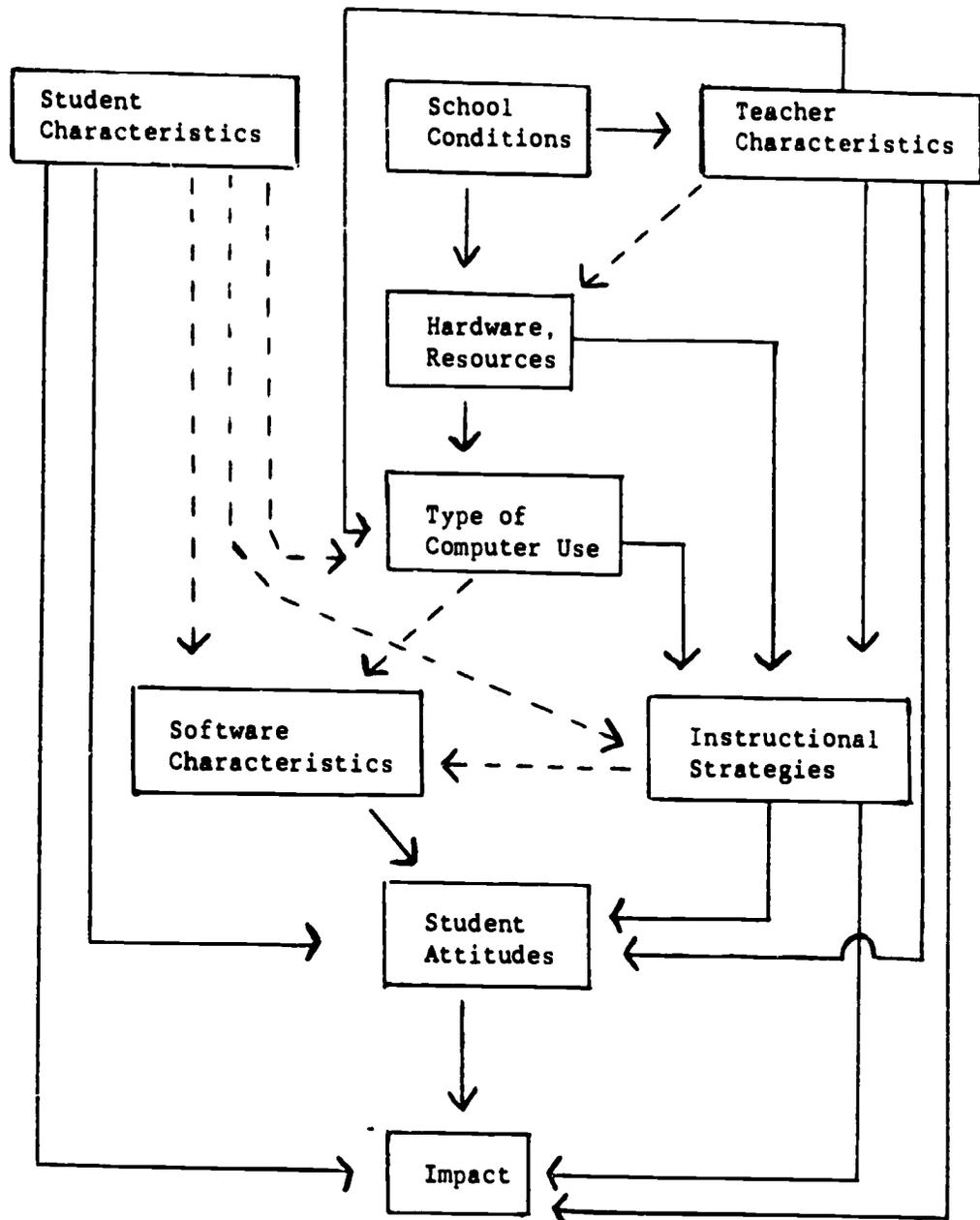
-Physical configurations

Interestingly, there is a virtual lack of research inquiry into the effect of various hardware characteristics on student learning despite the prominence that decisions about hardware purchase have in the agendas of decision makers in school settings. However, there has been some examination of the effects of hardware configuration and physical organization in the school--most notably, laboratory versus classroom--distributed--on student access and teacher/student attitudes about computer use (see Collis, 1988a, Chapter 10 for a summary). Martin and Preskill (1987) observe that many teachers using networked labs felt the labs provide "a valuable addition to teaching" but that "careful planning for implementation is critical, as is the principal's support, and a medium- to high match [of lab

activity] with educational objectives." Cheever and his colleagues (1986) note that a lab, "instead of integrating computers into the normal life of the school, keeps them separate from it" and "often becomes the province of a small group of 'experts'...so that others feel excluded." The impact of this sense of discomfort on subsequent usage can be considerable.

9. Combining the components into a hypothesized model for the impact of computers in the school context

Based on the research, and given the eight clusters of variables described in the previous sections, the model diagrammed in Figure 1 is hypothesized to represent the system surrounding the impact of computer use in the school context.



Hypotheses:

--- → Mediates the effect of

— → Influences directly

Figure 1. A model for the impact of computer use in the school context.

Although the model suggests some major lines of impact among variables, it is important to note that interactivity exists between all the clusters in the model. Some of the components of students' and teachers' characteristics are stable attributes; others, such as teachers' attitudes about computer use, are clearly affected by the status of the rest of the system at the same time as they influence it. Thus the hypothesized lines of interactive or direct effect are by no means meant to be a simplistic reduction of the influence network in the system. However, based on the research, these lines have potentially more impact on the overall state of the system than do lines which are not shown in the figure.

There are at least two radical hypotheses within this model. One is that software characteristics in themselves do not directly affect computer impact on students, because the impact of these characteristics is so strongly a function of other variables in the system, such as type of computer use, the effectiveness of the instructional environment in which the software is used, and the personal characteristics of the teacher and students who are interacting with the software. Another radical hypothesis is that teachers' instructional decisions are perhaps the major influence on eventual impact, both through their direct effect and also through their strong effects or moderating influences on other variables in the system, such as student attitudes and software characteristics. However, because the model represents a dynamic system, the equilibrium within it may well be situation specific, and therefore, in certain settings different variable clusters may dominate the system more than they do in others.

IV. Application of the Model to the Improvement of Computer Impact

Now that we have posited a model, what can we do with it? For one thing, we can attempt to test it, in order to validate its hypothesized paths of influences. However, this is a long-term research enterprise, and while critical, it may not appear to address the immediate needs of practitioners and decision makers, the same people who are asking us, "What works?" Fortunately there appears to be another way to utilize the model and this way has both practical and theoretical benefits. This approach involves examining the clusters and variables in the model through the perspectives of two sets of criteria: manipulability and critical upper/lower bounds.

1. Manipulability

1.1 Identification of manipulable variables. Clearly, some variables are more amenable to manipulability than others. For example, the variables within the student characteristics cluster are unlikely to be changed by practical intervention

strategies, nor are those relating to teacher's intellectual ability or depth of subject matter insight. According to the hypothesized model, these student and teacher characteristics have strong direct and moderating effects on the entire system influencing computer impact. This leads to some pessimistic observations about how much the system and therefore the impact can be manipulated; however, the strength of these variables in terms of eventual impact is consistent with experience and may underlie the observed variability in the impact of computer use in classroom despite continual improvements in software, hardware, inservice availability, and student and teacher experience with computers.

However, other variables in the model are clearly open to manipulation, although their necessary interactions with powerful student and teacher characteristics will mediate or even mask the impact of changes occurring through their manipulation. According to the model, instructional integration of computer use appears to be manipulable to the extent that it is not a function of personal teacher characteristics. Also, the model suggests that school support conditions, especially inservice opportunities, can have a powerful effect on ultimate computer impact, to the extent that these conditions inform or inspire teachers to utilize more effective instructional strategies when involving computer use within the students' learning experiences. Thus one function of the model is to focus attention on manipulable variables as entry points for influence over the system.

1.2 Priorities for manipulation. Another function of the model is to suggest some assumptions about priorities for intervention, or manipulative activities. Variables associated with software characteristics, for example, because they are going to be so much moderated by instructional strategies, may be less appropriate for intensive research and development focus than are the instructional strategies themselves and how these strategies may be influenced by manipulable aspects of school conditions and teacher characteristics.

The model also suggests that decisions about hardware configuration (not type of hardware, but how it is physically organized in the school) may have a more critical influence on the subsequent impact of computers than is usually considered, in that configuration decisions strongly affect the nature and extent of instructional integration of the computers into ongoing subject matter learning experiences. Teacher characteristics also mediate the impact of configuration decisions, as many teachers, for example, choose not to interrupt their preferred teaching routines in order to relocate student activity in a lab, or may feel uncomfortable about working in an environment perceived as the "territory" of a subgroup of staff in the school. Thus, well equipped labs in many schools are

underutilized, or not utilized at all, by the majority of teachers, and disproportionally overutilized by a small subset of staff, typically the senior secondary level computer science teachers (Becker, 1983, 1987b; Kass, Kieren, Collis, & Therrien, 1987; Martinez & Mead, 1988).

2. Critical upper and lower bounds

2.1 Defining critical bounds. The model suggests another approach to improving the impact of school computers. This approach involves the idea of critical upper and lower bounds for variables in the system. Critical lower bounds are defined as boundary conditions for particular variables below which the system as a whole is highly unlikely to be effective regardless of the value of other variables. Critical upper bounds in contrast are characteristics of particular variables that are powerful enough to make the system likely to be successful in its eventual impact regardless of other variables. It is, in fact, the latter which people implicitly hope exists when they ask, "What works?"...some computer application robust enough to emerge as valuable despite local situational variables.

2.2 Critical upper bounds for systems of variables. The interconnectivity of the model suggests that the appealing simplicity of this type of conclusion about a single critical upper bound is probably not realistic to expect. However, perhaps we can identify some combinations of certain critical values of teacher and student characteristics, type of computer use, school support conditions, and instructional strategies which can emerge, as a unit, to have a positive impact on student learning. Specifying the critical values for variable clusters considered as a unit within the overall system, and identifying which values are most amenable to manipulation within this unit may give us a systematic and realistic way to effect change in eventual impact, at least in certain situations.

An examination of the status of critical upper bounds in different cultural settings may also give us a more systematic approach for comparative research which in turn can help us eventually identify systemic conditions robust enough to influence positive impact of certain computer applications in different cultural contexts. This would truly be a powerful response to "What works?", if such a generalization is possible.

2.3 Critical lower bounds and their effect on the overall system. The aspect of critical lower bounds also merits serious examination, especially if these lower bounds are on variables not amenable to manipulation but highly influential in the overall computer impact system. Teacher intellectual ability of general instructional effectiveness may be such variables; for example, is it possible that computer/software characteristics can emerge as powerful enough to meaningfully improve learning

despite an unmotivated and ineffectual teacher? Or will such a teacher inevitably dilute or dissolve potential computer impact regardless of the values of other variables such as software and hardware characteristics? As long as teachers can choose to utilize computers or not, the impact of an unimaginative or negatively inclined teacher is a critical lower bound to the system, at the very least through the simple mechanism of the teacher deciding never to allow student-computer interaction to occur. However, even this is not as pessimistic as it seems; aggressive school policy can be developed that organizes systematic computer integration for all students through "team-teaching" arrangements with competent subject matter/computer specialists. Such arrangements can help override some negative teacher effects, at least with respect to ensuring all students some meaningful computer access.

3. Applying the model for intervention decisions

3.1 Application in the context of three general intervention approaches. The last example illustrates how the model, together with the ideas of manipulability and critical upper and lower bounds, can guide strategy for the improvement of computer impact in schools. A next level of consideration for decision makers involved in computer implementation in schools can relate to identifying effective mechanisms for manipulating critical variables or variable clusters in the system toward "upper bound" characteristics.

Three general intervention approaches are most common: increased funding, changes in national or regional policy, and changes in teacher training or retraining. These three strategies can be recommended in combination as well as separately. The model may be able to provide a productive framework for consideration of the viability of these approaches in terms of eventual systematic changes toward a "critical upper bound" state. For example, the call for more funding is a regular reaction to frustrations about limited effectiveness of computer impact in school. However, it is valuable for us to seriously question the contribution of more funding to certain of the key variables in the system. Which variables are most likely to be positively manipulated by additional funding? Are these variables the most critical influences within the system? Increased expenditure on software development, for example, may have little systemic payoff if effective improvement in teachers' deployment of embedding instructional strategies does not occur. Or as another example, increased expenditure on teacher training may have limited impact on the overall system if the training is not appropriate to the experience, personality, subject matter insight, and preferred teaching style of the recipient of the training. National policy that provides funding for certain hardware allotments to schools may vary in effectiveness depending on what decisions are made about teacher support and

about teacher and student access to the equipment as mediated by its presence in a lab or distributed more closely to familiar classroom situations. As a final example, better use of existing equipment may be a more advisable priority than expenditure on additional equipment, if work with familiar equipment can expedite teachers' development of instructional strategies and personal self-confidence while relearning new equipment can retard these sorts of developments and instead put the teacher back to a hardware-familiarity focus rather than an instructional focus.

3.2 Global benefits of applying the model. These sorts of considerations can provide dynamic tests of the productivity of the model as a framework for realistic improvement in the impact of computers in schools. The model presents an admittedly cumbersome and unappealingly complex answer to the original questions, "What do we know? What works?" but an answer which is at least honest in its representation of the complexity of the situation while offering entry points for intervention. If indeed critical upper bound characteristics, perhaps energized only in synergy with other critical upper bound characteristics, can be identified and if this synergy can be seen to operate in different cultural settings, then we will be able to make a response to "What works?" that has both theoretical and practical integrity.

This is our challenge as EURIT participants--can we, in our working groups, use the model to help us address questions such as the following:

- Where might increased expenditure be most effective in terms of improving computer impact in our schools? To what extent will responses to this question vary from country to country? From school to school?
- Where in the model are the most important targets for aggressive national policy support? Will these targets vary from country to country? What can we learn from each other's experiences with respect to the effect of policy decisions on eventual impact of some component of computer use in schools?
- Can we identify some combination of variables relating to student and teacher characteristics, type of computer application, and instructional strategy which is likely to result in a positive impact on learning? Will this combination be generalizable to a variety of of cultural and national settings?

Even if we can not achieve the isolation of critical upper bound combinations that the last question represents or reach a

consensus on issues relating to funding and policy interventions such as those in the first two questions, the model seems likely to make at least two contributions. First, it focusses attention on the complexity and interactivity of the system surrounding the impact of computer use on a particular learner, thus precluding any simple answers or prescriptions. Second, and perhaps most far-reaching, it can serve as a catalyst for a more general re-examination of the nature of teaching and learning. This kind of analysis is likely to be beneficial for the discipline of education in general, as well as for the learners whom we serve. Moonen (1985) captures this potential in his paper on the computer as an "educational psychiatrist":

The most explicit effect of using computers in education for the immediate future will be that this approach forces everybody to think again very carefully about what education is all about and how it can be accomplished. (P. 162)

To the extent that we contribute to this broad examination of educational issues, we will make a contribution to our field, even if the complexities of the network surrounding the impact of computer use in school continue to elude our control.

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