EDUCATIONAL INTERACTIVE SYSTEMS RESEARCH:
INSTRUMENTATION AND IMPLEMENTATION

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Abstract—In this essay we analyse why the introduction of computers in education has not so far proceeded as expected. Three perspectives are being used in this analysis: a technological, educational and administrative perspective. It is concluded that from a technological point of view, the evolution is going better than was expected. For the other two perspectives, the reality has not at all reached the expectations. We describe that, in order to cope with this mismatch, we are adapting by changing some of the concepts underlying the expectations in the technological, educational and administrative areas. As a result we claim that in order to stimulate progress, a pragmatic approach in conducting research that connects instrumentation and implementation has to be pursued.

INTRODUCTION

A joke is often based upon some partial truth. One such common joke is about distinguishing six phases during the execution of a project: (a) enthusiasm, (b) disillusionment, (c) panic, (d) search for the guilty, (e) punishment of the innocent, and (f) praise and honour for the non-participant. For the sake of argument, let us think along such lines, and consider the introduction of computers in education as a (very large) project, with many participants all over the world.

In this essay, we apply these six phases of the joke to a very serious area of research, that of computer-related educational instrumentation. We argue that the "computer in education project" indeed has gone through the first three of these phases, and that we are now at the point of having to find the guilty. After considering various candidates, we will conclude that we, researchers in this area, are indeed the guilty ones, through lack of appropriate instrumentation and implementation research.

WHERE ARE WE? A QUICK OVERVIEW

Phase 1

We have certainly gone through the phase of enthusiasm. In most countries this phase occurred in the 1980s[1,2].

Phase 2

After the initial excitement, at the end of the 1980s, the second phase of disillusionment occurred, as questions begin to arise about the impact of computers on education[3–5]. These questions about impact are difficult to answer. First of all, impact can be investigated from different points of influence: (a) impact at the curriculum level; (b) impact on the role of the teacher; (c) impact on the school as an organization; (d) impact on student achievement and motivation; and (e) impact on economic aspects such as costs, efficiency and effectiveness. Furthermore, at least two different applications of computers in education also should be distinguished: (a) learning about computers as a separate subject area, and (b) using the computer in the curriculum. And finally, a distinction should be made relative to levels of application: using computers in primary, secondary, vocational or higher education. Thus a simple answer to the question: "Does the introduction of computers have an impact on education?" obviously does not exist.

Nevertheless, the question in itself is of high importance, and many studies have been conducted to find at least partial answers to it. There are numerous articles which synthesize separate studies that investigate the effects of computers on education[6–8]. Most of these studies focus on student
achievement, performance and attitudes. Other studies, mostly of the survey type, investigate the factual use of computers in schools, the impact on the curriculum, and the impact on the role of the teacher[9]. Few studies however, focus on the impact of computers on the organization of the school[10]. And even fewer studies exist that focus on the economic aspect, in particular the costs, relative to efficiency and effectiveness when introducing computers in the schools[11].

Generally speaking, the introduction of computers as a separate subject area in schools (secondary, vocational and higher education) has been rather successful. The same conclusion can be drawn with respect to the introduction of computers in technically oriented subject areas in vocational education and higher education.

On the other hand there is still a very serious lack of integration of computers into the curriculum of the general subject areas in education. As a consequence, the role of the teacher and the organization of schools are only marginally influenced by the introduction of the computer.

With respect to the economic aspects of the introduction of computers in education, there are substantial differences of opinion[12,13].

Are we in Phase 3?

In terms of the six phases of a project in our opening joke, we can say that a certain level of disillusionment is occurring with respect to the impact of computers on general subject areas in education, on the role of the teacher, on the school organization, and with respect to the economic advantages. Do we face the same disappointment as has happened with many other technological innovations in the past[14]? Is there a panic? Who is the guilty? How should we proceed? In this article, we would like to investigate this line of thinking further.

WHAT DID WE EXPECT AND WHAT IS THE REALITY?

In many countries the introduction of computers in education was implemented within a large nationwide project, based upon a number of perspectives: (a) the technological level, (b) the educational level, and (c) the administrative level.

Technological perspectives

As computers are being introduced in most aspects of our professional and daily life, it appears obvious that the same should be happening in education. More specifically, the introduction of the personal computer in education is the best illustration of that evolution.

Expectations. As long as there has been technology, future projections of its development have also been present. Take the following two examples:

In 1985 it was predicted that in 1990 a personal computer would become available with the following specifications: a 32-bit central processor, a processing speed of 10 MHz, 4 Mb of RAM, and 2 Gb of external storage capacity available via an optical storage device, speech input, and capable of serving as a mobile terminal able to be connected to cable nets and television sets, and all within a price range of $10,000[15].

In 1988 Apple sponsored a competition among American students, to design the “Computer of the Year 2000”. The winners, a team from the University of Illinois, described a computer called TABLET[16]. The TABLET computer was the size of a notebook, with a LCD-screen but without a keyboard, can wirelessly be connected to all kinds of resources and telecommunication facilities, and uses as external storage capacity an optical rewritable smart card.

Reality. Price reductions, growing capacity for processing and storage, networking, multimedia, and telecommunications all illustrate that the growth in the area of information technology still continues and even that “the best is yet to come”.

It is clear that the predictions of 1985 have been realized. The latest developments, almost weekly being announced in computer magazines, developments such as the recent announcement of “digital assistants”, illustrate that what was predicted in 1988 will be available much earlier than the year 2000.
Conclusion. Mainly because of market competition, technological reality does not only live up to its promises, but is even doing much better.

Educational perspectives

Society is constantly trying to improve its educational systems. A recurring objective in educational reform programs is to better tailor instruction to individual differences among students.

Expectations. Individualized instruction was the main target of the programmed instruction movement in the 1950s. Since the 1960s the potential of computer-assisted instruction has been called upon to answer needs in education related to the individualization of instruction[17]. Over the years, this early focus on computer-facilitated individualized learning has not changed, with "intelligent tutoring systems" as the (current) ultimate representation of the individualization paradigm[18].

In addition, substantial impact was expected from the introduction of computers in education. Government involvement was mainly based upon expectations towards better quality of education, in combination with cost reductions[19,20]. It was believed that computers in education would open new opportunities, not only to the better individualization of instruction but also to a new level of richness in the educational environment.

Reality. As has been said in the introduction of this paper, expectations with respect to the educational impact of computers on education have been highly overestimated or disputed[21]. Even 25 years ago warnings were expressed about substantial differences between developments based on facts and those that are "disguised forms of science fiction"[22]. Lack of appropriate diagnosis, decision-making and feedback procedures in the context of computer-managed instruction add to the general picture that what happens in reality is far from what has been expected[23].

A recent study about the impact of the use of computers on children's achievement in primary and secondary schools concludes (again) that "the potential has been demonstrated", but also indicates that a lot has to be done, financially and through personnel resources "if this potential is to be achieved in schools throughout the country"[4, p. 166]. The same study also concludes that "how the software is used and integrated within the subject was entirely dependent upon the enthusiasm and skills of the teacher"[24].

The change process in schools as a result of the introduction of the computer can be compared with a steam-roller: "It takes much effort to get it started and, when it rolls, it rolls slowly, nothing can really change that"[25, p. 102].

Conclusion. What is happening in daily school practice is in sharp contrast with the expectations. Although the "potential" of computers being able to contribute significantly to solving problems in education has been demonstrated over and over again, the realization of that potential on a large scale, in "ordinary" and not "project" conditions, and in an integrated and stable way, hardly occurs, and when it does, the teacher is the significant contributing factor.

Administrative perspectives

Introduction of computers to support the administration and management of large organizations and to improve the efficiency and effectiveness of organizational processes has been a major goal since computers were invented. Gradually, as computers became widespread and available, such use has also been introduced in schools.

Expectations. In many countries there is a tendency to merge schools in order to create larger entities, and through larger entities to improve the efficiency of the organization and facilitate improved effectiveness. As a consequence school management has to become more business-oriented, and is being confronted with a growing financial responsibility. The principals and management teams in schools need to run their "businesses" in an appropriate way, and therefore need more management tools and data as support. In addition, national authorities want to improve the efficiency of nationwide educational systems, and are thus requesting an increasing amount of school data, to be delivered in electronic forms. Computers can provide the facilities to support such activities.
This trend is very well understood in education. In a recent survey, school administrators mentioned that the add-on value for the introduction of computers in schools mainly lay in the organizational and managerial uses of the computer[26,27]. School administrators expect that computers will provide them with the necessary means to collect information at the macro-level (in response to national requests), help them to make decisions at the meso-level (school and classroom) and provide information to be used by the teachers at the micro-level (the teaching/learning process involving individual students).

**Reality.** The decline in computer prices and a wealth of computer programmes to support administrative and managerial tasks have led to this kind of computer use being widespread in schools. Generally speaking, the collection of data at different levels has been established very well in schools.

The support function of the computer to analyse the collected data, to construct a diagnosis based upon the data, and to use the results in a decision-making process, is a much more difficult issue[28]. Because of this difficulty, improved efficiency and cost-effectiveness at the school level is far from being realized.

**Conclusion.** Schools are not different from other organizations in society. As in the “real” world, the effects of automatization projects in schools are appearing at a very slow rate. What is realized is certainly less than what has been promised and expected.

**SINCE WHAT WE EXPECTED ISN’T HAPPENING, DO WE NEED NEW CONCEPTS? HOW SHOULD WE ADAPT TO THEM?**

From the previous section it can be concluded that for none of the three perspectives—technological, educational and administrative, is the real situation what was expected. Because things are not as we expected, the concepts that were the bases for the expectations are now also being called into question.

**Adapting to new technological concepts**

Technological change does not occur as a response to specific needs in society (or education)[29,30]. In society two contradictory trends are occurring: (a) a trend toward centralization in order to improve efficiency, and (b) a trend toward decentralization in order to improve effectiveness. The centralization trend is most visible at the supra-national and economical level. The decentralization trend is most clearly occurring at the cultural and personal level.

Information technology is a major facilitator of both contradictory trends. At the economic level, information technology supports the efficiency of production processes in trade and industry. At the cultural and personal level, information technology facilitates individualized and personalized behaviour[31], and has the potential to improve the general effectiveness of human processes, and in particular, educational processes.

What are major developments in the information technology area? A typical activity lies in the area of subsystem configuration. Subsystems technology is heading towards a great variety of component substrates[32], with tasks directly being incorporated into microprocessors. At the software level, object-oriented design is the equivalent of subsystem configuration[33]. Both evolutions can improve the cost-effectiveness of software and courseware production. Further, there is the domain of user-friendliness, particularly as embodied by the icon/mouse/windows interface[34], better incorporating the use of humans' visual and audio senses. Another activity is the integration of information technology and telecommunications into distributed work and learning, leading to worldwide computer-supported collaborative group work and communication. Also there is the application of artificial intelligence methods in courseware engineering, trying to better deal with individual differences. However, as human learning still cannot be accurately modelled or measured, and present-day student models are still too simplistic and too static[35], the major problem remains how to determine what a machine ought to know and ought to say in order to respond effectively to what the user wants and needs[36].

**Conclusion.** The future of technological developments is relatively predictable. Adapting to its change patterns can create better and more cost-effective solutions for man–machine communication, and can provide better opportunities to adapt to individual differences. However, potential
improvements have upper bounds. Lack of theoretical foundations prohibits systemic dealing with the uncertainties of human behaviour[37,38].

Adapting to new educational concepts

The organization of the school, its curriculum and its instructional strategies are based upon educational goals. Such goals are influenced by philosophical perspectives or by issues that relate to developments in society. Philosophical perspectives and developments in society are changing over time. As a consequence, educational goals are also repeatedly changing and education experiences reform after reform[39].

New concepts for learning. For example, for almost a century now, philosophical perspectives underlying education have swung between constructivism and behaviourism, while developments in society have kept moving between conservatism and socialism. As a consequence schools and their goals and objectives are a moving target, which makes it difficult to agree upon general educational policy, instructional strategies, and the development of specific instructional material.

Systematic approaches, mostly based upon instructional systems design methodologies, have tried to cope with this great diversity of opinions[40]. Experiences indicate however that in practice the suggested systematic approaches are only partially functional[41,42]. To find solutions, points of view based upon behaviourism have been complemented by perspectives based upon cognitive theory, which by the way, have triggered a fundamental discussion about the appropriateness to the previous paradigms[43-45]. Some fundamental educational concepts are changing, accompanied by new approaches on the use of information technologies. These concepts include: (a) constructivism—the knower constructs or interprets reality based upon his experiences[46]; (b) situated learning—learning occurs most effectively in context, (c) cognitive apprenticeship—teachers should focus on approaches to solving real-world problems reflecting the reality of the learner rather than utilize predetermined instructional sequences[47]; and (d) cooperative learning with computers[48].

Those new approaches have brought important insights to the design of electronic environments to support learning. At the same time, expectations based upon such new educational concepts must be confronted with the real and pervasive limitations of the school environment. The new approaches are not the panacea for instructional problems in education and training[49].

Pendulum effects and pragmatism. The current discussion and controversy within instructional design and instructional theory is a typical illustration of the pendulum movement so characteristic for education at large. As such, this discussion should not get too much emphasis. In contrast, the choice of instructional strategies and the development of instruction/learning material should be much more based on pragmatism; pragmatism based upon available and affordable resources such as information technology, but mainly upon available teacher expertise. Illustrating this approach, Fullan[50] has stated that successful examples of innovation are grounded in what might be most accurately labelled “organized common sense.”

Conclusion. As a consequence of the ongoing change of educational concepts, the application of information technology in education has gone through different phases[51,52]. Looking back however, none of the old concepts nor their adaptations, nor the new educational concepts present a stable direction upon which to build. Educational and instructional theory do not provide us with reliable guidelines about how to organize and instrument education[53].

Adapting to new administrative concepts

National governments are faced with growing financial problems. Budgets for national education have to decline, and schools are being directly confronted with constraints. In the past, in many countries allocating money from national authorities to local authorities was mainly based upon a top-down approach, whereby schools got a budget based upon and allocated toward certain predetermined characteristics. Recently a reversed approach is getting momentum. The basic idea is a bottom-up approach, whereby schools get a much more global budget and a growing financial responsibility. This approach is based upon the opinion that the school itself has the best insight about how to allocate resources and optimize its activities. The autonomous school is the central concept in this context.
Cost-effectiveness. Although not new as a concept and mainly because of financial constraints, the notion of cost-effectiveness is also getting more attention. There are widespread misconceptions about what is meant by costs, efficiency, effectiveness, cost-benefits and cost-effectiveness[54]. Besides confusion about the terms, building a cost-effective model and implementing measurement of relevant factors constitute even more substantial problems. In a study published by UNESCO[55] more than 100 potential cost functions and effects are listed that could be taken into account in any cost-effectiveness approach. The report did not, however, give any advice as to how to measure them, especially when the effects are of a qualitative nature[56].

On the one hand, thinking along cost-effectiveness lines is almost compulsory, given the financial problems faced by educational systems. On the other hand, thinking along cost-effectiveness lines is almost impossible, given the difficulties establishing appropriate models and methodologies and the measurement of the chosen items.

Current approaches tend to circumvent the problem. At the national level, financial problems are shifted towards the local authorities: the local authorities have to deal with it, and find “cost-effective” solutions. Therefore schools are forced to merge, in order to gain some financial benefits from enlarging their scale, to use computers to strengthen their administrative and managerial processes, and to streamline the efficiency and effectiveness of their internal processes.

Performance support. At the classroom level cost-effectiveness problems are very rarely dealt with[57,58]. Some new teaching/learning approaches however are evolving which could, eventually, contribute to the cost-effectiveness issue. A new concept called Electronic Performance Support Systems (EPSS)—a system to provide whatever is necessary to support performance and learning at the moment of need[59, p. 34]—is appearing, particulary in training settings. Another interesting and connected concept is “Information technology-based open learning (ITOL)”[60], also called “Just-in-Time” open learning (JITOL)[61,62], in which open learning and computer-mediated communication are combined.

In comparison with traditional computer-assisted instruction or computer-based training which are built up of predetermined presentation sequences, those new approaches are often based upon an interactive, hyper-referenced information base that can be accessed in multiple ways, accompanied by a broad range of support mechanisms (advisory, problem structuring and decision support)[63]. Some[64] already claim that as traditional classroom teaching gets steadily more expensive and unproductive, it will be replaced by cheap and more powerful “hyper-learning” technology, of which EPSS and JITOL could be forerunners.

The new concepts of EPSS and JITOL can create the opportunities to search for those resources that fit specific circumstances, and therefore could increase the effectiveness of the learning/training activity. What will be necessary, of course, are powerful navigation and decision-support tools, to help the selection process involved in using the resources. The big advantage is that with such a concept, resource material can be produced with a broader range of applicability, helping to bring down the production costs. Examples already exist. “On-line help systems”, for example, are available in word-processing systems. This approach coincides with the “modular” and “reuse” concepts in computer science.

Conclusion. Because of the lack of theoretical models, the issue of cost-effectiveness can hardly be solved for specific products. Using resource-related approaches, and providing powerful navigation- and decision-support systems, directions can be explored which perhaps may result in specifying the cost-effectiveness of specific processes, instead of specific products.

WHO IS THE GUILTY? WHO SHOULD BE BLAMED AND HOW SHOULD WE PROCEED?

From the previous sections we can derive that the evolution of information technology in society presents a fast-moving but stable direction, with as its major characteristic: continually improving support to deal with individual processes and differences. We also concluded that, due to lack of theoretical models, no clear direction exists with respect to educational policy and instructional strategies, nor is there a straightforward approach toward a cost-effective implementation of learning and instruction.
Consequently, we feel that the choice of instructional strategies and cost-effective implementations should therefore be based upon pragmatic points of view, taking into account individual and local circumstances, and making optimal use of the developments in information technology.

Phase 4: search for the guilty

Arriving at this stage in our analysis, we would like to refer to our starting point again, and the joke we used as a metaphor. In that context questions were raised about a sense of disillusionment with respect to the introduction of information technology in education. In our analysis we came to the conclusion that such disillusion certainly exists. Who is to blame for this disillusion? Maybe many have to be blamed: (a) the technologist for evolving too fast, not allowing the educational system to cope at a reasonable pace with new developments; (b) the educationalist, for not being able to provide instructional and learning theories as a basis for the establishment of reliable instructional strategies; and (c) the administrators, for lack of creativity to apply cost-effectiveness perspectives to decisions about the use of information technology. Referring to the joke we could respond: “When everybody is guilty, nobody should be punished but neither should anyone get praise and honour”. Should therefore everything continue in the same way? How to proceed?

Towards a new strategy to stimulate the introduction of information technology in education and training

With a pragmatic approach as the leading principle, and since learning/instructional material is often the basis for teaching/learning activity, the “instrumentation” of the teaching/learning environment should be a central activity. By “instrumentation” we mean the realization of teaching/learning material designed to fit the physical environment in which it has to be used. Such instrumentation should take into account the local logistic circumstances and history, the didactical preferences and expertise of the teacher, as well as individual differences between students.

Products of the first and second kind. In practical terms, the creation of a teaching/learning environment should be an assembly task done by the main local actor: the teacher. For that purpose, the teacher should be able to select and assemble material from a broad resource base of information, and be supported by powerful tools in order to do this. In addition, such info-databases should contain results of research connected to the use and implementation of the material. Such an approach relates to what earlier has been described as electronic performance support systems or just-in-time education.

What is necessary for such an approach are different kinds of products. The basic products are information resources, and tools and procedures to extract, assemble and manipulate the learning material. These products are called “products of the first kind”. The authors of such products are called “first authors”. Products of the first kind should be highly modular, from a content point of view, as well as from a technical point of view. Each product should contain an “external shell” that has its hooks and connection points to other modules. Based upon such basic products, teachers should be able to combine such modules and resources and transform them into material fitted to their own needs. As such, “products of the second kind” occur. The authors of such products are called “second authors”.

It is the role of information technology specialists to provide developers and users with tools and generic services to create, reuse, interchange, manage and distribute multimedia and hypermedia-organized information. Again, given the evolution of information technology and the stable direction of its evolution, it is almost certain that those facilities will become available, with steady improvement of functionality. Publishers, as managers of information, should take the lead in distributing such products and tools[65]. When the industry succeeds in agreeing on standards in this area, it is highly probable that this approach will also lead to economic advantages.

Although experiments with these kind of approaches are already occurring[66], much of this is still in the future and therefore should make us cautious. As has been done so many times in the past, we should not make ourselves guilty of building up false expectations about new sorts of environments with different approaches to instrumentation. However, this approach could become the new strategy to support the use of information technology in training and education.
**Instrumentation and implementation research**

This new strategy should not distract us from our main task, to find reliable theories about teaching and learning, or more specifically, about the instrumentation of educational environments. Given that perspective, what should be the main research directions?

Build on small successes, at the local level, from real practice. Be pragmatic; if it works, try to identify factors that seem to be present. Bit by bit, build tentative hypotheses based on practice. In this way, theory can gradually emerge and unwarranted expectations can be better avoided. Such a research approach coincides with pleas for "more local theories" [67].

**Relating these arguments to the organization of this Special Issue**

In the Introduction to this Special Issue, a categorization of research was presented. In it, the editors suggested: (a) the Describe–Understand–Explain Phase, where the intention is to look insightfully at a particular context, to see what is happening in that context, and to try to explain it; (b) the Multiple-Loop Instrumentation–Implementation Phase, where the intention is to bring a particular version of instrumentation or implementation to a local setting, test its fit to the context, revise the instrumentation or implementation strategy, and test its implementation again; and (c) the Hypothesis-Testing Phase, where a traditional comparative research design is used.

The kind of research that we have called for, discovering the main characteristics of local successes and their associated instrumentation, is research of Category (a). As the local successes are furthered and fine-tuned, this becomes research in Category (b). After a number of local iteratives, a local theory can tentatively emerge and be tested. This is research in Category (c).

After collecting the results from research in (a), (b) and (c), new insights can emerge, as a new loop of a next spiral of observation, fine-tuning and local experimentation also described in the Introduction to this Special Issue. In that new research loop, existing practice, or practice adapted to the possibilities of the newest technology, or augmented by products of the "second kind", can be investigated in more complex situations. Eventually new insights and expectations, built up in consecutive loops, will be tested in real-world situations, providing experiences and data that in turn can contribute to a theory of educational instrumentation.

What has to be realized however, is that it can take a long time before the instrumentation-implementation research loop has evolved to a satisfactory solution. In the meantime, information technology will continue to evolve, and will provide other, maybe even nicer possibilities. Very often, however, given the new possibilities of information technology, researchers do not take the time to do the hypothesis-testing loop, but instead start all over again, with research of Types (a) and (b). Consequently, too little reliable data, resulting from hypothesis-testing research, is being gathered. Furthermore, too few data are provided to contribute to theory building.

**CONCLUSION**

We wrote that in our area no cohesive instrumentation theory exists. The fact that only a limited amount of research of the hypothesis-testing type is being done in our area certainly affects the lack of a theory. Earlier, we concluded that everybody, and therefore nobody, is guilty for the sense of disillusionment that is occurring in the area of computers and education. Maybe we were wrong. Maybe we, as researchers in this area, are the guilty ones because we are not doing the research that we should do.

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