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Computerized Simulation: An Overview

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Various issues and practices related to computerized simulation are outlined, particularly in relation to the other papers in this special issue of *SSCORE*. These cover such aspects as learning as both pedagogy and research, the "philosophy" of simulation, the relations between and the relative prominence of simulation techniques and computer technology, and various problems related to modelling, design, evaluation, and assumptions. *Keywords*: computerized simulation, computers, learning, modelling, pedagogy, research, simulation, simulation design, simware.

Two developments have recently caught the imagination of both educators and researchers: computers and simulations. When these two are combined, we have a potentially very powerful methodology; indeed some of the most interesting educational software includes simulation, and many of the more powerful simulations contain some computer element. Many types of simulation are ideally suited to the computer, and the computer is often an ideal medium for simulation. The promise of computerized simulations is intimated in Kaye's (1984) description of the computer itself:

> The protean nature of the computer is such that it can act like a machine or like a language to be shaped and exploited. It is a medium that can dynamically simulate the details of any other medium, including media that cannot exist physically. It is the first metamedium, and as such it has degrees of freedom for representation and expression never before encountered and as yet barely investigated. Even more important, it is fun, and therefore intrinsically worth doing.

The term *computerized simulation* (CS) refers to a simulation which, in some form or another, includes the use of a computer. It may mean a simulation which has (literally) "been computerized," that is, an originally manual simulation which has had part or all of its parameters and

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structure adapted for working with or within the computer, or it may refer to software initially conceived and programmed in the form of a simulation, often with additional manual materials. The first type has been tackled from the simulation end, the second from the computer end.

Learning

However a CS may be conceived, learning remains the *raison d'être* of simulation. This issue aims to show how computer technology and simulation techniques may be combined to produce an extremely powerful medium for learning. Learning here is taken in a very broad sense to include both research and pedagogy. Research entails learning something about the world, and so does pedagogy, whether it is substance or skills. However, these two broad modes may overlap, as in the pedagogy of research.

Research simulations may comprise at least four learning aspects: (1) professional research instruments to generate data and ideas in such areas as policy and decision making (e.g., *MT. ST. HELENS*, by Ekker, Gifford, Leik, and Leik); (2) theory-testing devices (e.g., *IFS*, by Hughes); (3) media to enable students to experience research in a relatively safe and inexpensive environment (e.g., *PROJECT SIMULATION*, by King and King); and (4) objects of research themselves (e.g., Feinberg's concern with people's reactions to unexpected results, or research into certain aspects of simulation processes or outcomes; see Watson and Sharrock [1987]).

Pedagogical simulations may be categorized by a number of interlocking criteria, for example, institutional level or learning objectives and outcomes. They may be educational techniques or professional training instruments. They may be used for teaching facts and knowledge or as heuristic devices for understanding complex relations or research procedures. They may contain an explicit effective dimension (e.g., for changing attitudes) and they may help in the development of skills (e.g., in management, policy formation and implementation, decision making, research).

The papers in this symposium show that CSs may be used for more than one purpose. For example, *COOPERATION & CONFLICT*, by Oppenheimer and Winer, can be used for teaching about both concepts and research. The two terms in the subtitle of this issue derive from this broad range of learning concerns. *Issues* has to do with points of debate among scholars and practitioners, while *practices* refers to the more pragmatic research and teaching applications. The papers in this issue all address these strands in varying degrees. But the above remarks raise the thorny question, touched upon later, of the exact nature of learning and its evaluation.

Chicken or Egg?

Simulations existed long before computers were invented, but the two media have been associated ever since computers came onto the scene.

Indeed, it was a major game theorist, Jon Von Neumann, who designed one of the first modern computers (EDVAC). First, computers were appended to simulation, mainly as number crunchers. Then, in the late 1970s, simulations were designed explicitly for the computer; their shape was determined by the capabilities of the computer. More recently, especially with the advent of the flexible microcomputer (e.g., Acorn BBC, Apple II, IBM PC), there has been a movement back to using the computer more as a peripheral aid, as one among a number of components, in simulation.

Simulations and computers have had a mutually beneficial effect. There is little doubt that the advent of the microcomputer has conferred a greater legitimacy upon, and promoted a more widespread use of, simulation. This is not to say that computers determine, or should determine, simulation characteristics; rather, it is an indirect commentary on the fact that just as other educational media (e.g., paper, video) have their limitations, so do computers. One might say that simulation has come to the rescue of computer use in the classroom. The earlier CAL programs showed little imagination and tended to promote rote learning in a sort of programmed instruction sequence (a somewhat euphemistic name for this is "tutoring programs").

The modern microcomputer was enthusiastically hailed as a solution to many of the teaching problems of the time, the operative word being "teaching." Recently, however, a more enlightened attitude has developed, in which the main focus is placed upon the learner and the learning process. For many years simulation/gaming has recognized this; indeed, the basic philosophy of simulation/gaming is that teachers cannot learn for their learners, that the teacher is only a facilitator of learning, and that first-hand experience, active involvement, and enjoyment are at the base of all effective learning. A simulation, by creating a rich and challenging environment, provides that experience and allows participants to become actively involved. A computer does not by itself provide such an environment; what it may do, though, is to enhance simulation procedures (e.g., by carrying out complex calculations). Indeed, two recent volumes on educational computing group most of the papers on simulation under "teaching strategies" and "learning environments" (Kent & Lewis, 1987; Moonen & Plomp, 1987). As Oppenheimer and Winer point out in this issue, the computer, by helping to make certain boring and time-consuming procedures transparent, allows participants to concentrate on the main objectives and concepts without getting bogged down in complex and abstract equations.

Thus, the initial enthusiasm over computers has been tempered by a sense of realism and by the realization that it is not the computer, with all its finery (graphics, sound, etc.), which enhances learning, except of course that in education it does have the major advantage of removing the teacher from center stage in the classroom and of at least dampening his or her potentially negative feedback. At first the computer seemed to provide the answer, because it was ideally suited to manipulating some of the variables and complexity inherent in many simulations. But, as some of the papers in this issue demonstrate, we have begun to realize that many factors simply cannot be satisfactorily computerized, at least not without adopting some form of simulation, and so designers have begun to attend more to the learning and modelling aspects of their CSs.

Shifting Emphasis

The luster of new fads wears off; now people want "better" courseware. Simulation software (or "simware") has come to be recognized as one of the most sophisticated kinds of courseware and as possessing the greatest potential for a range of purposes, especially when the CS is designed not from the computer end, but from the model and learning end. This is not because of the computer, but because people have paid greater attention to the simulation aspect of CSs. Although CSs have enormous potential in education, training, and research, they still tend to be used less than other types of courseware. In education generally, the use of computers (without simulation) remains more widespread than the use of simulation (with or without computers).

The focus on computers may be due to the educational philosophy behind the use of simulation, or it may reflect a perception of CSs as being entirely computer phenomena, or again it may have something to do with the fact that a computer is a concrete object, whereas a simulation is an activity and thus much less palpable. Perhaps some types of simulation require too great a change in student-teacher relationships and are therefore felt as threatening by teachers who cannot see that a student fully engaged in a task is less of a threat than one who is led by the marks carrot to grind through dull drill tutorials. Perhaps, too, teachers are disconcerted because many CSs, especially the more recent ones, are open-ended, that is, provide no right answer. One objective of education should be to give students an opportunity to develop a tolerance for ambiguity, to say without worry, "I don't know, and that's okay." Whatever the reasons, it is safe to say that teachers are often more worried about these problems than students, and that the proper use of simulation often requires a more radical shift in teacher and administrator attitudes than does the use of computers.

The situation, however, may not be as bleak as it appears, especially in the more enlightened educational settings. The growing prominence of simware in computer circles is clear, and a recent shift in emphasis is discernible. For example, educational computing conferences are attended by many gamers, and simulation conferences are attracting more computer enthusiasts. Educational computer publication too is evolving; see, for example, Garson (1987) and of course this special issue.

Design and Evaluation

Computerized simulations combine both computers and simulations. But how far have simulation people joined the computer camp, or how much notice do computer people take of what is happening in the simulation camp? The distinction may be little more than academic, but it does have a bearing on such aspects as the design of CSs and the way they are used. For example, are CSs best designed by computer buffs or by gamers? The papers in this issue amply demonstrate that attention needs to be given to both components, and that a successful CS requires the expertise of both simulation/gamers and computer specialists. However, given that a simulation is usually based on some conceptualization of reality (i.e., some form of model), it is the general simulation design which more often than not determines the role of the computer, rather than the other way about. The simulation characteristics are paramount, and the computer configuration follows from these. Technology serves substance.

A simulation is only as good as the model it embodies, and it will work well only if conducted properly. However, the computer is important, too, for it not only contains at least some components of the model but also influences the way in which the simulation is designed, built, and run. In the design process, a model is generally constructed first, and then a suitable computer medium (machine and software) is sought, but the computer constraints may in turn influence the final simulation configuration. Simulation design is a complex process (see, for example, Greenblat [1987a]), and the addition of a computer complicates it further. Excellent accounts of the CS design process are provided by Knox, Robinson, and Stoneman in their account of *ZIMOD* and by King and King in their discussion of *PROJECT SIMULATION*. Other papers, too, address specific aspects of design, including the choice of hardware and software.

Computer people tend to present simulation as something new and wonderful; simulation people tend to consider the computer simply a tool in a range of game paraphernalia, along with such items as dice and boards. Thus, gamers tend to ask, "Is a computer necessary?" and "Does it add anything to a simulation which might be just as easy to run and just as effective in achieving its purposes without a computer?" Computer people must by definition use a computer, and when they discover simulation, usually through some CS, they may see it as a way to show off the computer. Here, questioning the need for the computer is self-defeating.

Fortunately, this is not true of the papers in this issue; indeed, they are all good examples of well-thought-out exercises which have been designed as simulations, not as reasons for using the computer, or, worse, as show pieces for the computer. The danger is that in designing CSs there will be less concern with the simulation than with the computer. There is far more to a CS than the simware or gameware, as papers in this volume attest. The simulation inevitably determines the role of the computer, not the other way around.

Many studies have been carried out on the effectiveness of simulation, and as many again espouse the advantages of simulation with little in the way of research support (see, for example, research reviews in

Greenblat and Duke [1981]). The usual problems of educational evaluation are compounded by the specific nature of simulation/gaming activities, which are very different from those commonly encountered in the traditional classroom setting. We have probably not yet fully understood what we may measure in simulation, let alone how we may go about it.

> What exactly is, and happens in, a simulation determines both what these things are, what they can be used for, and how effective they can be. Their effectiveness has not been overwhelmingly demonstrated; many variables intervene. But, it seems that what these things actually are and what really goes on in them are vital questions which must be posed in any attempt at systematic assessment as to their "effectiveness." If, as we have attempted to show, simulations are not entirely what we think, or are inclined to think, then the measuring instruments we have been using to evaluate them are probably not the right ones. If we are trying to measure simulations (or their effect on the participants) in terms of their representivity, but realize that their greatest impact is in terms of their reality [in their own right, and not as representations of some external "reality"], then we are measuring the wrong thing, or rather we are trying to measure temperature with a barometer.
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> Participants often report very high levels of motivation, but traditional evaluations show that simulations do not always do better than classic methods, especially in the learning of facts. How easy is it to make accurate and consistent measures of such things as empathy, the reality defining and negotiation processes, insight into complex relations, broadening horizons, and a whole host of ordinary everyday experiences? And why would we normally wish or even need to measure them? If, as we suggest, the answer to the first question is "not at all easy," then we need to recognize that we have a learning technique which we can only argue for, not prove. If the answer to the second question is "because we wish to please the educational administrators," then we are fighting a losing battle. Both questions address the issues from a representational angle, but the meaningful answers can only be provided from within the reality perspective. (Crookall, Oxford, & Saunders, 1987)

Issues and Practices

All the papers in this issue demonstrate awareness of the above aspects and issues, even if only implicitly, for example, by way of discussing the limitations of the computer components in the simulations described. A great many issues related to computerized simulation are raised in the papers. Most tend towards concern with the modelling or simulation end of the spectrum; a few are related to the computer part. It is difficult to separate these two aspects, since, for instance, issues related to the type of model will entail certain programming features, while the constraints of the computer will influence the model adopted, the simulation design, and the way the simulation is run. Indeed (although authors were in no way instructed to do so), many of the discussions in the papers revolve more around simulation than around computer issues. The authors' major concerns have to do with the simulation side of the CS, though they must inevitably address computer considerations. A great many issues and practices are covered in the papers, including disciplines and skills, research, and computer and simware problems.

Computers and simulations, being essentially content-free, have proved useful in almost every discipline. The papers in this issue deal with a wide range of subject areas and skills. A range of social sciences as well as decision-making skills are at the center of the article by Joe Oppenheimer and Mark Winer. Barry Hughes focuses on international relations and global modelling, while Philip Schrodt explores foreign policy decision making and strategic behavior. Jon Knox, Peter Robinson, and Colin Stoneman use simulation as a decision-making aid in national economic planning. Behavioral sciences, particularly psychology, are discussed by Alan King and Barry King. Knut Ekker, Greg Gifford, Sheila Leik, and Robert Leik are concerned with social relations, particularly family behavior under natural disaster conditions. Bill Feinberg examines the intuitive assumptions people make about social policies. In the Communications section of this issue, important elements of social psychology are examined in two CSs by George Holden.

Research considerations are the main focus of some of the simulations, but the theme runs through many of the papers. *COOPERATION & CONFLICT* may serve as a pedagogical tool to teach research methodology in the social sciences, but it may also be an instrument for generating data. *PROJECT SIMULATION* is essentially a pedagogical tool to help students understand both the methodological principles and the detailed procedures of psychological research. *MT. ST. HELENS* is an instrument used to generate data about family responses to natural disasters, and the authors emphasize that similar techniques may be used for research into other phenomena. *IFS* may be used in more theoretical research, to test out different theories used in global models. *ZIMOD* is more a heuristic device, but it may be conceived of as a research instrument to help national decision makers. Feinberg's paper also deals with research into reactions to unexpected results of modelling social policies.

Readers of this journal will be well versed in general issues related to the computer, but there are issues associated specifically with simware, as opposed to other types of software, that relate to the purposes for which the simulation is designed and used. The papers published here thus cover many of the issues and practices related to the computer side of CSs. Authoring systems for CSs have been conspicuously absent, but Oppenheimer and Winer have clearly demonstrated their power and usefulness. Developmental costs of simware are touched on in a number of papers, particularly by Oppenheimer and Winer. The type of programming language is usually chosen after the basic model has been worked out, when the designer has a clear idea of what the simulation is expected to do. Knox, Robinson, and Stoneman spend some time explaining clearly why they chose Pascal, while other authors mention their own reasons. The need for clear and structured programming, especially if the simware is to be used on a number of machines and upgraded as newer machines come on to the market, is emphasized by King and King. Artificial intelligence (AI) is an avenue that shows much promise in CS, not least of all because AI and CS have a great deal in common. The tools of AI are being used more and more in the simulation of complex systems, especially those that exhibit variable and varying structures (see, for example, Elzas, Oren, and Zeigler [1986]). *PWORLD* by Schrodt is an excellent example of how AI is being used.

Finally, two major concerns arise over modelling. The first relates to the role of the computer in the overall model, and is a major design problem encountered at the conceptualization stage. Decisions have to be made about which parts of the model should be contained within the computer and which should remain in the hands of participants. Many solutions are illustrated here, ranging all the way from an all-machine simulation (*PWORLD*) to a simulation in which a major portion of the whole model remains outside the computer (*MT. ST. HELENS*). The related problem, equally tough, is deciding how complex and abstract to make the model. This is, of course, a question with which simulation designers have always had to grapple, even before the advent of the computer. The question, though, becomes more critical when a computer is used. It is not that the computer itself is a complex thing; it is that by making the computer responsible for certain parts of the model, a number of further questions arise. For example, although the computer may make some processes easier or more transparent, the designer has to be clear about such points as what exactly the computer is up to, how the computer interfaces with the other aspects of the model, how participants perceive the "hidden" computer part, how human communication patterns are to be simulated (see Law-Yone [in press] for a useful discussion), what types of participant behaviors emerge, and how control over simulation events is managed (for a discussion of some of these issues see Crookall, Martin, Coote, and Saunders [1986]).

Pitfalls and Prospects

As I have said at several points, simulation is in itself a particularly powerful methodology. The addition of a computer certainly makes it even more so, but, as I have just mentioned, this raises further questions and may even mask deeper questions we should be asking. There is thus a danger that in developing ever more sophisticated and "intelligent" tools we will forget to stand back and examine them critically. It is only through such scrutiny that pitfalls can be seen and corrected. As the authors here show, open-mindedness, interdisciplinarity, healthy skepticism, and fertile minds are imperative.

I should therefore like to sound a note of caution: we will do well to ponder some of our basic assumptions and taken-for-granted attitudes. The following arguments may seem provocative, or even heretical, to some, but they are ones we must consider in our quest for a healthy critical appraisal of our endeavors and in particular of our assumptions about the relations among modelling, simulation, and reality, as well as those about the influence of information technology on simulation and its methodological task. In raising these complex issues, I can do no better than quote at length from two sources. In the first, Bob Anderson questions the validity of modelling, particularly in the humanities and social sciences, and the assumption that a simulation is a working model of some portion of reality. In a lucid and well-argued paper, Anderson (1987)

> considers one conventional view of the relationship between models and reality, a view which is termed "the representational conception of reality." This conception is found to be inadequate, first because it does not describe the essential and inherent discontinuities between games and reality, and second because it relies heavily on presuppositions about the use of models in science. The presuppositions have recently been under attack by various contributions in the philosophy of science....
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> The defences which ... game constructors offer for the pedagogic and research relevance of their games turn upon the strength or adequacy of the model on which the games are based. Thus, games are defensible because they are "realistic" in some sense. This realism derives from the thoroughness and systematicity of the method by which the model is derived. The model genuinely represents how things are. The simplifications and condensation embodied in the model are to be treated as temporary infelicities which, with a closer attention to detail, will be ironed out....
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> And yet, the arguments of Putnam (1981) and Cartwright (1983) indicate that all this effort is misplaced. It is directed to justifying game usage in terms of a conception of modelling thought to be derived from the practice of physics and natural science and invoked as the template for methodological rigour, adequacy and exhaustiveness. In accepting that this conception of modelling was, indeed, the standard to which they ought aspire, game constructors ... have set themselves an impossible task.... Once free of the obligation to match up to and emulate what is felt to be the proper method for developing knowledge as that might be demonstrated in physics, the justification for the use of games and simulation can be couched, not in the realism of the models, but in other ways. One such might be in the nature of games themselves. The focus of attention will switch away from representation to what Ian Hacking (1983) calls "intervention"—the process of constructing, planning, organising and playing games and simulations as means for reproducing specifically designed versions, simulacra, of facets of the natural and social worlds in which we live.

Those are indeed sobering remarks, but we should also consider the computer side of CSs and address the possible danger of allowing information technology perspectives to influence our view of simulation activity and our attempts to understand the world through simulation. In so doing, we need to raise

> another issue, one discussed by Berlinski (1976) in a brilliant and scathing attack on the use of cybernetics, information theory, systems analysis and computer modelling, particularly in the social sciences (and it is to be noted that Berlinski addresses the models that underlie simulations, too). He points out that the employment of such cybernetic models in the social sciences may lend an apparent "quantitative scientific" modern and technical cast to the disciplines, but which in fact possesses a permissive, *ad hoc* and essentially woolly, indeterminate and logically incoherent quality. Cybernetics quickly takes on the soggy, poultice-like quality of the disciplinary framework into which it has become incorporated, claims Berlinski. This, we feel, is a contentious but serious point to be considered in relation to some uses of computers.... Should it be assumed that computer models always add something to some pedagogical or analytic task in hand? Or, as Berlinski might lead us to believe, does the apparent technicality of these types of models detract in some way from the ordinary, less glamorous employments of the discipline's routine arts, crafts and conceptual devices of pedagogic and analytic work? Along with Berlinski, we can simply note here that there can be no *a priori*, "disembodied" answer to this question; rather we have to examine the use of computer modelling on a case-by-case basis. (Watson & Crookall, 1987)

The papers in this collection show either implicitly or expressly a concern for these issues, and that is a healthy sign. So I should like to finish on an optimistic note by quoting from Dick Duke, one of our foremost gamers. He had this to say nearly a decade and a half ago, and it is even more pressing today:

> More than ever before, man needs to be able to reminisce about the future, to explore "what if" questions in involved and highly speculative environments.... It is beyond human comprehension to deal with the present in a detailed and factual way, and equally impossible to do so for alternative futures. Indeed we need heuristic, overview, or gestalt perception from which we can derive an orientation toward the future that will provide us with crude guidelines for action. Gaming/simulation is one prospect for assisting us with this task. (Duke, 1974).

Simulation/gaming is indeed a rich and potent technique; when computers are brought to its aid and used judiciously they can considerably enhance the technique. Together, the papers in this volume demonstrate the natural symbiosis of simulation and computers in a new form of learning known as computerized simulation. The versatility and flexibility of CSs make them potentially very effective as learning vehicles. The papers here are certainly witness to the richness and sophistication which can be accomplished with CSs, and which probably no other pedagogical or research medium can ever hope to emulate. I think we can agree with Versluis (1984) when he says that "there are enough clearly identifiable advantages to justify optimism that computer simulations will play a major part at the far reaches of computer-assisted instruction."

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