ADVENTURE GAMES FOR TECHNICAL EDUCATION

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Abstract

This paper describes the use of adventure games for technical and scientific education. The topics most appropriate for instruction via adventure games are those such as chemistry and physics that require knowledge of abstract concepts and mastery of advanced problem-solving skills. Adventure games that teach such topics can be constructed as a network of rooms in which each room represents a concept or skill and the paths among the rooms reflect the conceptual structure of the subject matter. Each room offers the player an opportunity to practice the focus skill or explore the focus concept for the room. Ancillary support for learning can be provided via conventional computer- or text-based instruction, hypertext, and visualization techniques.

Games of this sort offer signal advantages over conventional computer-based or classroom instruction. Their motivational advantages are clear. Properly constructed they allow the student to conceptualize the structure of the subject matter in terms of the game topology, thus bringing the power of spatial cognition to bear on the difficult task of conceptual organization. The adventure environment can immerse the student in the subject matter in a way that is often impossible in the real world. Instructional exercises can be focused on critical learning objectives thus increasing time on task. Instruction can be adaptive so that students devote only the time needed to master the subject matter. Visualization techniques can be used to convey difficult abstract concepts.

Cost effective development of computer games can only be accomplished if the dual nature (instruction and entertainment) is recognized. The market for instructional adventure games is often not the same as the market for commercial games. Special mechanisms (e.g. hypertext) are required to meet instructional objectives. Prototypes and other mechanisms needed to ensure that instructional methods and content are effective.

Biography

Dr. Halff is a research psychologist with twenty-five years of experience in learning, instruction, and instructional technology. His broad range of skills covers high-level research planning, bench-level R&D, and instructional design. In his current position at the Mei Technology Corporation, he manages a research program on generative, knowledge-based instructional technology. He also conducts research on the use of computer games for science education.

Before joining Mei Technology in 1993, he owned and operated a successful consulting firm, Halff Resources Inc., where he designed and developed both conventional and computer-based instruction for maintenance, management, sales, and other areas. Prior to founding Halff Resources in 1984, he worked for seven years as a scientific officer in the Psychological Sciences Division of the Office of Naval Research. There, he developed a reputation in scientific, military, and government communities for his management of research programs in the rapidly advancing fields of educational technology and cognitive science. These highly acclaimed programs reflect his expertise in computer-based instruction, applications of artificial intelligence to instruction, and applied aspects of cognitive science. He came to the Office of Naval Research from the University of Illinois at Urbana-Champaign, where he was an Assistant Professor of Psychology (1970-1976). His activities there covered mathematical and cognitive psychology, and he specialized in models of learning, decision theory, computer-based research, and statistics. He was an NIMH postdoctoral fellow at the University of Michigan's Human Performance Center in 1969-1970. In 1969 he earned a doctorate in Psychology from the University of Texas at Austin

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INTRODUCTION

In the Summer of 1991 a colleague who works for the Navy called me to ask if I would be interested in developing a computer game to teach budding avionics technicians about basic electricity and electronics. I asked, "You want to pay me to do this?"

"Sure," he replied, "I figure It will take you and a couple of graduate students." In the Summer ol 1993, a team considerably larger than me and "a couple of graduate students" delivered a version of a game known as *Electro Adventure* that taught part of what students in the Navy's Avionics (AV) "A" School needed to know about capacitors and capacitance.

This paper is partly the story of the development of *Electro Adventure* and partly an exposition of the lessons I learned in the course of that development. You should know that, by choice, I functioned as *Electro Adventure's* instructional designer. Thus, the treatment below focuses on instructional design. Our software designer and game designer would give entirely different stories. The Navy Personnel R&D Center conducted an empirical investigation of the game's effectiveness and will have yet another story to tell.

I hope to package the following remarks in a form that will be useful to those developing similar products, namely, computer-based adventure games for technical and scientific education. To determine whether you are among this audience, you will need to know what I mean by “technical and scientific education" and by "computer-based adventure game."

The Subject Matter

Technical and scientific topics of the sort addressed by *Electro Adventure* have several interesting characteristics.

- Technical and scientific topics rank high on the difficulty scale. Parents of high-school students, I suspect, hear more complaints about Chemistry than Social Studies, and qualifying for technical schools in the services is a considerable challenge. Hence, any instructional approaches that bring these subjects within the reach of more students should have a considerable market.

- Of more instructional relevance is that these topics can often be characterized by a network of concepts. Figure 1 shows the network that makes up some of the concepts addressed in *Electro Adventure*. Note that a prerequisite relation structures the network in that some concepts cannot be mastered before others. For example, one cannot understand how RC circuits charge and discharge (2.2 in Figure 1) before one knows what an RC circuit is (2.1 in Figure 1).

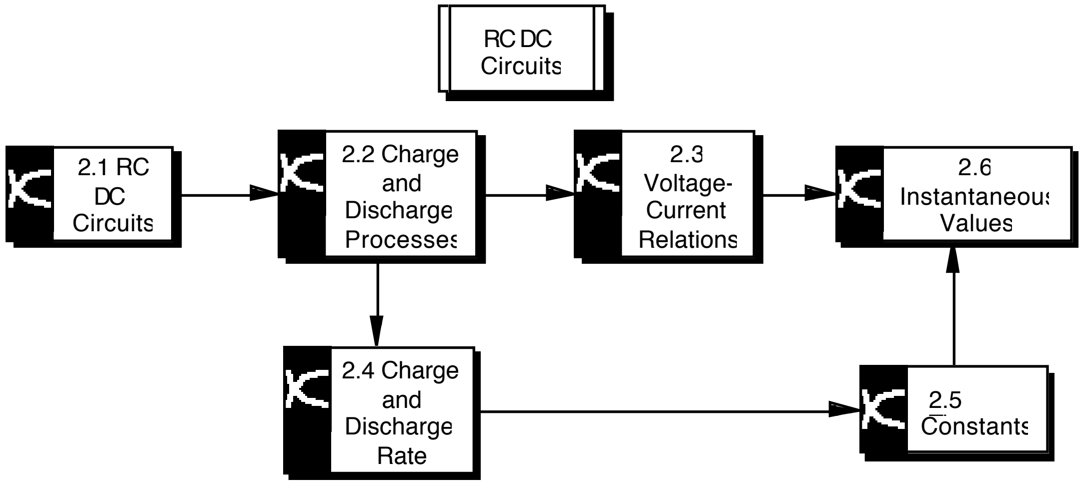

Figure 1. Concept Network for a Segment of *Electro Adventure*

- Another important characteristic of technical and scientific education is an emphasis on quantitative problem solving skills. Even the most elementary chemistry course requires students to solve problems involving combining ratios of elements and concentrations of chemicals in solution. Students in the Navy's AV "A" course must be able to find the equivalent capacitance of multi-capacitor circuits and to determine instantaneous circuit quantities at particular points in charging and discharging cycles ol resistor-capacitor (RC) circuits.

- A fourth important characteristic of the subject matter found in technical and scientific education is the importance of qualitative knowledge. Much of the difficulty in mastering technical subjects lies in the importance of abstract variables such as electrical current, and the constraints among them. A primary goal of technical education is that of teaching students to reason about the behavior of these variables, and the difficulty in acquiring these reasoning skills has much to do with the fact the variables are several steps removed from actual experience.

It was these four characteristics of technical education—their challenging nature, the structured character of the concepts, the critical role of quantitative problem solving, and the importance of qualitative reasoning—that struck me, and still strike me, as making this type of subject matter promising for the application of computer-based adventure games.

Computer-Based Adventure Games

Computer-based adventure games are computer games in which the player assumes the role of a character in some fictional scenario. This character can move around in the environment defined by the scenario, carry and manipulate objects in the scenario, and converse with other characters. The environment itself consists of a network of regions, typically called "rooms." In *Electro Adventure*, the environment was a ship named the Electro. Figure 2 shows the topology of one section of the Electro.

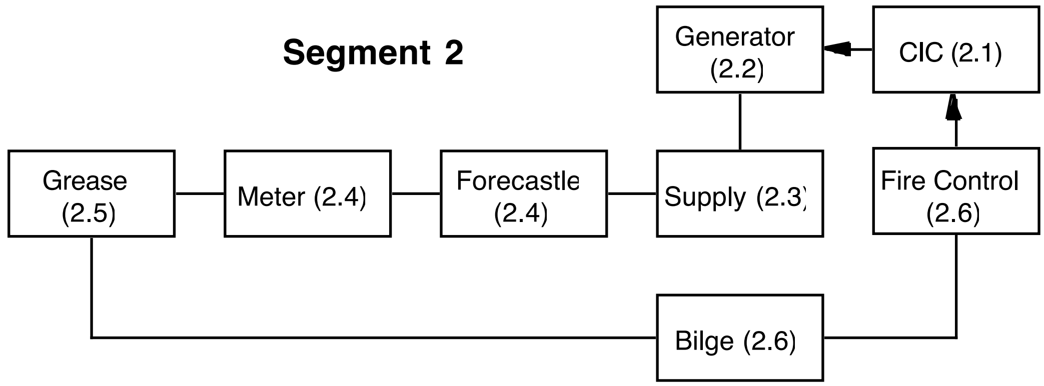

Figure 2. Topology of the Section of the Electro Addressing Topics Shown in Figure 1.

Some games such as *Super Mario Brothers* rely heavily on psychomotor skills; others rely on the player's ingenuity and problem-solving skills. It is this latter sort of game that is of interest here since they offer the most promising opportunities for education. Examples include *the King's Quest* series published by Sierra On-Line and *Loom*, published by LucasFilm. These games have many goals, including survival, material gain, amassing points for accomplishments, exploration of the environment, and achieving some particular objective such as rescuing a damsel in distress. Strong motivational characteristics constitute one of the many reasons for applying adventure games to technical and scientific education.

To elaborate, two well known limitations of conventional training and education are lack of opportunities to practice the skills being taught and failure to sustain motivation over the long periods needed to achieve competence in the target skills. Adventure games address both of these problems by providing for extensive practice in an environment that is almost certainly more motivating than conventional education and training. It is also possible in these games to present to students situations and problems that are not feasible to present in the "real world. "

In addition, all of the benefits available in other multimedia instructional software are also available in adventure games. Chief among these benefits are opportunities for the use of hypermedia and the application of animation to visualization of complex scientific concepts.

The fantasy aspects of adventure games also offer unique advantages for instruction. Students are able to practice skills and apply knowledge in semi-realistic environments. Although these environments do not offer all of the features of the real world, they can be constructed to convey important lessons about the application of technical skills in real world situations.

In some respects, fantasy environments are superior to real-world environments in that they can be designed for an optimal instructional sequence and to maximize the student's time on critical learning tasks. In fact, I feel that the best of these games provide a level of immersion in the subject matter that is impossible to achieve in the real world, classroom, or laboratory.

Finally, adventure games offer a natural way of mapping the structure of the subject matter to the topology of an adventure game. In *Electro Adventure,* for example, the tasks or challenges found in each room address a single topic in the curriculum. Furthermore, the topology of the game is derived from the network structure of the topics. Figure 2, for example, shows the topology of the section of the Electro that addresses the topics on RC DC Circuits shown in Figure 1. Notice that students cannot enter the rooms addressing higher level topics before they have visited the rooms addressing their lower-level prerequisites. Mapping game topology to the structure of the material in this fashion is a natural way of enforcing prerequisite relations. Perhaps more importantly it allows students to bring spatial cognition to bear on the difficult problem of developing a conceptual structure for the domain under study.

ADVENTURE GAMES FOR INSTRUCTION

Adventure games designed for instructional purposes will, of course, differ in many ways from those designed for entertainment, and the topology-topic correspondence is only one distinguishing characteristic of the former. A picture of these distinguishing characteristics emerges from an examination of *Electro Adventure.*

The Scenario

Electro Adventure's scenario centers on a ship, the Electro, that, through a mishap has been transported from the future to the present time. The mission of a player is to find the resources needed to repair the ship's computers and return her to the future. Accomplishing this mission requires the traversal of a number of rooms, or rather compartments, on the Electro. Each of these rooms addresses a single concept, topic or instructional objective, which we will call the room's *focus.*

Instructional Mechanisms

Figure 3 shows the student's view of a typical room in Electro Adventure. The student can explore the room, discover objects therein, containers that themselves contain objects, and characters of various sorts. Instruction in the room's focus is delivered in two ways.

Figure3. Typical Room From *Electro Adventure.*

The student may be required, on his or her own, to discover certain technical tricks needed to survive in or escape from the room. Failure to use proper safety procedures may, for example, result in the student's death. As another example, the student may be required to correctly combine materials and parts found in the room in order to manufacture some equipment needed in the game.

In most rooms, the student is also required to solve a series of technical problems of the sort typically found in textbooks. Figure 4 illustrates such an exercise from *Electro Adventure.* These exercises have several important characteristics.

- Students are provided with a special interface to the problem-solving environment by zooming to a problem view like that shown in Figure 4.

- The sequence of problems provided to the student can be graded in complexity.

- The parameters of each problem are randomly chosen so that students can obtain additional practice by replaying the room.

- An additional benefit of this feature applies when the game is played in a social setting. Students helping each other through the game cannot provide answers to individual problems since no two students see the same problem. Hence, help and advice must focus on the strategies and procedures for solving the problems.

- A performance criterion can be imposed to ensure mastery of the skills addressed by the exercise.

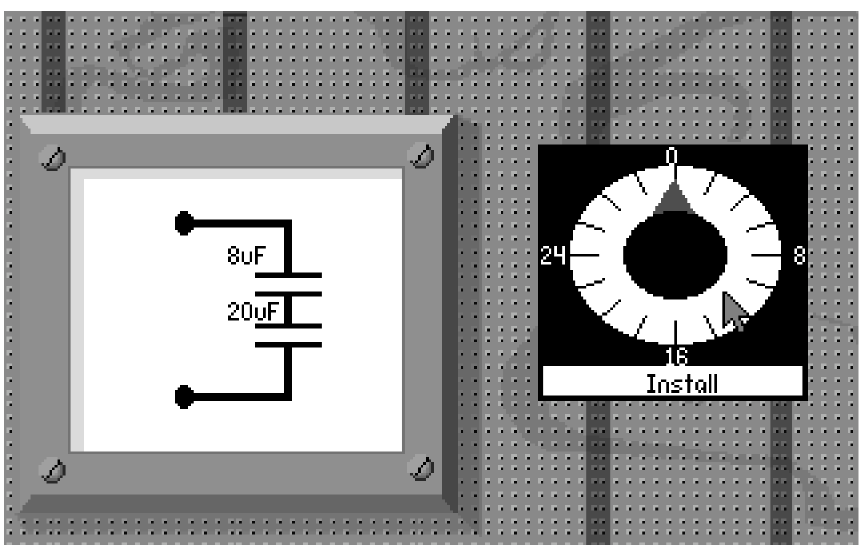

Figure 4. Typical Problem View from Electro Adventure. (Note: In this exercise the dial must be set to the equivalent capacitance of the circuit in the panel.)

Instructional support for each room's focus is also provided by a conventional *Computer-Based Training (CBT)*Lesson for the room. The lesson consists of a series of frames containing instruction on the room's focus. Certain interactive devices such as multiple-choice questions are used to maintain attention and ensure comprehension of the material.

A *Hypermedia System* is also available to the students for purposes of remediation, review, and exploration of the subject matter. The hypermedia system chosen for *Electro Adventure* is an adaptation of a product called *Thoughtsticker* developed by Paul Pangaro. The system consists of a set of topics defining the domain and a network of presentations used to present information on these topics to the student. The mapping of topics to presentations is many-many and complex, but the complexity is typically hidden from the student. Students using the hypermedia system are given a menu of topics relevant to the focus of the current room. The system, based on its past interaction with the student, uses heuristics to choose the most appropriate presentation for any chosen topic. Embedded in each presentation are links to other topics, and hence other presentations.

Employed by both the CBT and hypermedia system are *Visualization* techniques used to illustrate complex technical concepts. In *Electro Adventure,* for example, color and animation are used to show how current and voltage change over time in various parts of an electrical circuit.

The general principles of computer-based visualization are the use of color and animation as concrete representations of abstract quantities, and the capability of the student to control the parameters of the system being visualized.

Finally, a student interface is required along with other mechanisms to support the operation of the program itself. Among the components of this Operating System are a tutorial or guide to the student interface, mechanisms for saving the game state and other data, and a means for setting game preferences such as sound level.

THE DEVELOPMENT PROCESS

Design and development of a product such as *Electro Adventure* can be a major effort. In this respect, adventure games are more like movies than computer programs. The credits that roll at the end of a game such as *Kings Quest IV* list a host of artists, musicians, animators, and a few programmers. Major software houses such as LucasFilm and Sierra On-Line have developed sophisticated facilities for production of remarkably lifelike scenery and action.

Fortunately, non-commercial instructional games do not necessarily require the extensive effort and facilities involved in commercial efforts. The latter must compete in the marketplace where an extra 10% in sophistication and realism can mean the difference between success and failure. Instructional products often have no competition apart from conventional classroom or computer-based training. The degree of realism and sophistication need not be as great as that of commercial products.

Talent and Resources

Still, development of any sort of game is beyond the capabilities of one person or even an instructional designer working with a couple of graduate students. The development team for

Electro Adventure gives a good indication of the kind of talent needed to develop an instructional adventure game.

- A sponsor, the U. S. *Navy*, provided funding. In addition it defined the overall research goals of the effort.[1]

- A client, the Chief of Naval Technical Training provided the particular instructional objectives to be addressed in the game. In addition it provided subject matter expertise and an environment for evaluating the product.

- The program was managed by the University of Central Florida's Institute for Simulation and Training (IST), the Navy's prime contractor. Dr. Bruce MacDonald was the project manager for IST.

- An instructional designer (myself) worked with an instructional developer, Ms. Catriona Borbato, at IST to provide the instructional design.

- A game designer, Mr. Howard Delman, developed the fantasy used in the game and provided guidance on software development.

- A software design and development team at IST, headed by Mr. Ron Klasky, developed the software for the game.

- Computer-graphic artists (under the direction of Dr. Jackie Morie at IST) and a musician provided art for the product.

- A hypermedia designer, Dr. Paul Pangaro, helped with the implementation of the hypermedia system.

The Process

The process used to develop *Electro Adventure* was chaotic, to say the least, and only informative as a guide to what not to do. I therefore take the liberty of describing not what how the game was developed, but rather, how I would develop it if I had the opportunity to start over.

Development Facility. Create a development facility. This facility should have the following elements.

- An *Adventure Language* should be adopted for describing adventure-game scenarios. At least one such language (TADS) already exists.[2] Although it is specialized for text adventures, it is extensible, and, with some modification, it should serve to describe the adventure games of

[1] Three Navy organizations contributed to this effort under the umbrella of a program known as the Skill Enhancement Program. Participating were the Navy Personnel R&D Center, Op-112, and the Chief of Naval Education and Training. The Naval Training Systems Center managed the effort for the Navy.
[2] TADS: The Text Adventure Development System--Version 2.0, a shareware product (O 1992) by Michael J. Roberts.

the type considered here. The language not only provides an important prototyping tool but also formally defines the possibilities for the game scenario.

- A *Student Interface* should be designed that implements the semantics of the adventure language. That is, the specification should denote how actions in the game are depicted on the display and how actions by the student influence the course of the game.

- A *Hypermedia System* should be provided. This component may, and probably should, be nothing more than a commercially available hypertext shell.

- A *CBT System* should be adapted to provide the lessons addressing the focus of each room. As with the hypermedia system, this component could be an available commercial product.

- A complete description of the student interface and support system should be provided in the form of a Users Reference Manual This manual should describe all general options available to the student at any time and the effects of exercising those options.

Instructional Design. The instructional design determines the content of the game. It should have the following components.

- A *Conceptual Map* details the instructional objectives of the game. It should consist of a network like that of Figure 1 together with a narrative description of each concept in the network. Also required for accountability purposes is the relationship of each concept to the course's instructional objectives. Typically, concepts will be cast at a greater level of detail than instructional objectives so that several concepts will be required to cover each instructional objective.

  The conceptual map is the basis for all subsequent development. It's structure determines the topology of the game scenario. At a more detailed level of elaboration, it determines the structure of the hypermedia system. Since the CBT component is keyed to rooms, the conceptual map also determines its structure.

- The *Adventure Scenario* describes the adventure's environment, objects, characters, and other characteristics. It consists of four components:

  - a map showing the game's topology (see Figure 2),
  - a narrative description of the game's rooms, characters, objects, and special effects,
  - a formal description of the game in the Adventure Language described above, and
  - sketches illustrating the rooms, objects, characters, and specia effects.

- The *Exercises Design* describes the exercises to be delivered in each room. It includes

  - narrative descriptions of the exercises,

- the procedures to be used to generate exercises on-line,

- illustrations of the student interfaces to the exercises, and

- prototypes of the exercise-generatior procedures.

  Such prototypes, although not strictly necessary are the most efficient way to refine the exercise-generation procedures and to present them to subject-matter experts for review.

- The *CBT Lesson Scripts* are a complete set of scripts for all of the CBT Lessons, including the text of each lesson and sketches illustrating art and animation to be employed in these lessons.

- The *Hypermedia Design* consists of a list of topics to be used in the design, a description of the collection of presentations, and a specification of the network defining the structure of the hypermedia document.

Development. If the development facility is properly designed, the development process itself should be almost routine. Major steps in development include

- the conversion of room, character, and object sketches to computer graphics for integration into the game,

- the development of software for the exercises based on the exercise design,

- the development of CBT lessons based on their scripts, and

- the entry of data into the hypermedia system.

LESSONS LEARNED

The product and process described above illustrate one approach to the design and development of instructional adventure games, and, in fact, the approach is by-and-large untried. In order to provide a larger perspective, it is fitting to conclude with some of the lessons that we learned in the course of developing *Electro Adventure.*

- Pitch the product design to the intended market. The initial design goal for *Electro Adventure* was a product that would be competitive with the best found in the commercial market. As the result, many expensive artistic effects were included that contributed little to effectiveness. A more appropriate design philosophy would have recognized that the real competition for *Electro Adventure* is an instructor and chalkboard.

- Constrain the complexity of the game scenario. The game scenario in *Electro Adventure* was written without any regard to the programming challenges that it might present. Indeed, because of lack of experience, the programming team could not even anticipate which aspects of the design would prove to be difficult. By using a formal language, you can impose a discipline on the game design by restricting the scenario to one that can be represented in the Adventure Language and its student interface. You can also simplify software development by explicitly separating room exercises from the adventure's scenario.

- Provide tools and products for early review of the design. Most of the paper design documents proposed here were also produced in the course of designing Electro Adventure. However, these paper descriptions were completely opaque to the Navy's subject matter experts (and to many on the design team itself). As the result, no meaningful reviews could be conducted until the project had been committed to code, at which point changes were exceedingly expensive. To remedy this problem, you can to provide more sketches and working prototypes of the exercises so that quality can be assured before programming begins.

- Include all components in the design. In *Electro Adventure,* as in other projects, major features, most notably the hypermedia system, were inserted into the project after the initial design and some development were completed. The inclusion of these unplanned for capabilities were the source of considerable stress on the product development process. There are considerable benefits to committing the project to the design as written.

As a final note, you may be interested in a preliminary look at the evaluation conducted by the Navy as mentioned above. This evaluation consisted of a single experiment in an AV "A" school. In this experiment, Electro Adventure was pitted against stand-up instruction and two other Computer-Based Instructional (CBI) systems developed at NPRDC. The results were mixed.

One indication, of singular importance to the students, is performance on the 40-item test that they are required to pass. Table 1 shows the mean percent correct on this test. for each group. *Electro Adventure* did not fare too badly by this standard. Worth noting in this regard is that we had access to the testing instrument during development and were amply warned of the dire consequences should students fail the test.

Table 1
Percent Correct on Evaluation Tests

Group	Stand-up	Electro	CBI 1	CBI 2	Std Dev
Unit Test	89	86	84	81	11
NPRDC Test	68	67	75	74	13
IMMS	12	13	12	14	na
N	13	23	24	20	

This was not the case with another test developed at NPRDC by the same team that developed both of the CBI lessons. Results on this 47-item instrument show some superiority for both of these CBT conditions over stand-up instruction and the game. The test was developed in the final stages of instructional development and therefore had no influence on the development of Electro Adventure.

NPRDC also administered a motivational measurement questionnaire, the Instructional Materials Motivational Scale (IMMS). As Table 1 shows, *Electro Adventure* did not show any particular superiority on this instrument. To understand this result, it helps to know that the questionnaire itself was not particularly oriented towards the motivational strengths of computer games. Although there were some questions that related to the instruction's ability to hold one's attention, many of the questions inquired about the relevance of the instruction and the student's confidence that he or she had achieved mastery. *Electro Adventure,* by the way, fared particularly poorly on the confidence scale.

In understanding the results of the evaluation in general, it is helpful to know that *Electro Adventure* in its current version suffers from extensive technical flaws including software bugs, inaccurate technical content, flaws in instructional technique, and human-interface problems. Despite these problems, it fared well on the single criterion that was most important to us as developers, and it did not do too badly on other criteria.

It also helps in understanding these results to take the proper perspective on the state of the art in this arena. *Electro Adventure* is, to my knowledge, the only computer game that seeks (with some success) to be a complete replacement for instructional techniques that have evolved over years in the particular school and millennia in general.

My ambitions for *Electro Adventure* were the same as those of the Wright brothers at Kitty Hawk, namely that it would fly. That it not only flew but also carried the freight was both gratifying and unexpected. The data in Table 1 constitute the first point of the learning curve for this very new technology. Although these data do not constitute a strong recommendation for *Electro Adventure* itself, they do indicate that investments in improving the technology would be well worth the expense.