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ABSTRACT

This paper reflects on the author's participation in two government-sponsored educational software development projects that used a holistic design paradigm in which classroom formative assessment and teacher input played a critical role in the development process. The two project were: R-WISE (Reading and Writing in a Supportive Environment)--a learning environment to teach writing at the ninth and tenth grade level, and BioBLAST (Better Learning through Adventure, Simulations, and Telecommunication)--a content-rich learning environment that mirrors research being carried out at several NASA centers. In both projects, high school teachers were part of the design team from the beginning, and both alpha and beta versions were field-tested in classrooms. Characteristics that classroom experts believe should be instantiated in truly effective educational software are described. Features that enhance the teacher's effectiveness in the learning process by allowing them to become mentors and facilitators include: developing bridging activities for clarifying and reinforcing concepts; using "artifacts" to foster learning; and sustaining the sense of a community for scientific inquiry. Features that encourage students to become active participants in problem-based learning include: improved strategies for inquiry; enhanced communication and publishing competencies; and increased understanding of the relationship between information manipulation and concept formation. (AEF)

Teacher-Driven Design of Educational Software

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In this paper, I reflect on my participation in two government-sponsored courseware development projects. Though neither project was modeled on the other, both used a holistic design paradigm in which classroom formative assessment and teacher input played a critical role in the development process. The two projects were —

- R-WISE (Reading and Writing in a Supportive Environment) – a learning environment to teach writing at the 9th and 10th grade level. The project was a timely collaboration among the military, business / industry, and the educational community to address one of the most pressing challenges facing our nation: teaching the thinking skills necessary to participate in a complex, modern society. R-WISE was developed by the Air Force's Armstrong Laboratory in partnership with MacArthur High School in San Antonio, TX. Over the course of the project (1990-1995), the software was implemented in several different states and used by thousands of students (Carlson, Hitzfelder, Hudson, & Redmon, 1996).
- BioBLAST (Better Learning through Adventure, Simulations, and Telecommunication) – a content-rich learning environment that mirrors research being carried out at several NASA centers. The project (1995-present) consists of simulations, microworlds, and interactive multimedia based on NASA's Controlled Ecological Life Support Systems (CELSS). Sustaining humans in colonies beyond earth's environment requires a balance among components and systems. Focal points of research include: (1) plant production, (2) human requirements, and (3) resource recovery. The target audience is 9th and 10th grade biology. Using the "tools," laboratory activities, and collaborative interaction, student teams design and balance a closed biosphere to support a crew of six, living on the lunar surface (Carlson, Ruberg, Johnson, Kraus, & Sowd, in process).

In each of these projects, high school teachers were part of the design team from the beginning, and both alpha and beta versions were field-tested in classrooms, representing adequate numbers and diversity to make the feedback useful. But more than these similarities, in each project the "development team" was as a multi-talented collaboration involving domain experts, instructional designers, software engineers, curriculum writers, and classroom instructors. The teachers were regarded as fully-vested members in the process.

Educational Software — Promise and Puzzlement

Increasingly, K-12 educational technology has come to mean some form of computer-mediated product. More affordable hardware, increasing awareness of new media (information technology in general), and the combined push from reform mandates and the pull of marketing for new media all contribute to an environment of rapid change.

Yet, reports both from the workplace and from higher education indicate that meaningful integration of advanced information technologies is not a matter of simply making the hardware / software available. For example, Geoghegan (1994) estimates that of all the educational technologies implemented in higher education, no more than five percent of instructors use computers as anything more than high-tech substitutes for the blackboard and the overhead projector.

On the K-12 level, many multimedia educational products available today are conceived of as "superbooks." They present students with multi-modal representations of materials and explanations, but their "pedagogy" is primarily didactic and their assumptions about learning are fairly static. Increasingly, we are seeing a backlash in the popular press against advanced educational technologies. The claims center on charges that most software engages only at a superficial level and — over time — both "deskills" the student and "disenfranchises" the teacher.

In general, educational software has not reached its potential for a variety of reasons. I suggest that these inhibitors can be clustered under four categories:

- Lack of meaningful formative evaluation – While change is in the offing, the current-traditional design methods for courseware/educational software do not include adequate feedback loops. Although this may be typical for an "immature" industry, it is to be hoped that developers of educational technologies will at some point have as much regard for product design and end-user needs as does the automobile industry.

- Emphasis on the student as end-user – Certainly, the learner (primarily, the learner's measurable achievement) drive much of today's concern for educational reform. However, a technology-enabled curriculum should be conceptualized as a dynamic partnership among three agents: the student, the teacher, and the computer-mediated learning tools.
- Lack of a robust new paradigm for technology in education – Education's recent history contains several examples in which a new entity emerged in a glow of promise but never reached fruition. We seem to be at that awkward transition point for computer-mediated learning — one in which the old methods are falling away, but the new paradigm, enabled by advanced information technologies, is not apparent.
- Overemphasis on teachers as technophobic – Too often, the teacher's role in technology adoption has been characterized as inhibiting and conservative. While advanced technologies may be a threat to some instructors, dwelling on negative "attitude" and on the need to "educate" teachers on hardware and software operation misses the real strengths teachers can bring to the process.

Collaborations for Progress

Figure 1 accounts for a spectrum of features in the "ecology" of education. This model suggests systematic and defensible design/evaluation of software / courseware in situ to promote "best teaching practices." Furthermore, the model implies consideration of a range of issues including integration of information technologies into existing curricula (easing the transition from traditional to innovative), establishing creative partnerships among students, technologies, and teachers, as well as selecting courseware /software for specific needs.

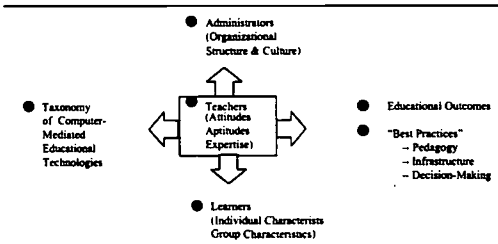

Figure 1: The Ecology of Educational Technologies.

As indicated in this schema, the teacher is the nexus for many issues of integration / implementation, administrative policy, assessment, and educational reform. The remainder of this paper extracts from the teacher commentary in both BioBLAST and R-WISE a set of characteristics these classroom experts believe should be instantiated in truly effective educational software. I will present these observations under two headings: first, features that enhance the teacher's effectiveness in the learning process; and, second, features that encourage students to become active participants in the learning process.

Software that Allows Teachers to Become Mentors and Facilitators

For this section, I will look specifically at the BioBLAST project, and focus on how this content-rich learning environment embodies emerging changes in science education. The radical shift away from lectures, decontextualized experimentation, and textbooks demands a great deal from the teacher. The move to authentic, situated, and project-based learning mandates that teachers drop their authoritarian mantel and assume a master-apprentice relationship with the learners.

All of the BioBLAST teacher-leaders are accomplished educators who have enthusiastically adopted the new role for teachers of science. They were selected to work with the project through a nation-wide competitive application process. Their specific charge in the first fielding (1996 - 1997) of the BioBLAST CD-ROM was two-fold. First, as classroom experts, they were asked to comment on the appropriateness of the materials for their situation. Second, as skilled practitioners of the new pedagogy, they were asked to facilitate the "weaving" of patterns of effective usage from the many available activities. In essence, teachers were asked to serve as "sherpas" in finding paths of learning through the rich and intensive environment.

During the academic year of 1996 - 1997, teacher-leaders adapted the components of the program to their individual situation, providing feedback on their experiences and adaptations. I summarize here three specific software features driven by the teachers' remarks.

Developing Bridging Activities for Clarifying and Reinforcing Concepts

Students — even the most enthusiastic of learners — have few mature strategies for constructing meaning from even the most well-planned of classroom activities. Thus, the BioBLAST teachers underscored the need for devising software activities that model complex concepts or behaviors in small or more familiar domains of experience.

For example, most classes approach BioBLAST as a long-term, project-based activity within which to examine important biological concepts. The overall theme of the photosynthesis / respiration cycle between humans, plants, and the external environment lends itself to "energy usage" as a starting point, with progressively more complex examination of basic processes occurring as additional cycles (carbon, nitrogen, water, decomposition, respiration, and combustion) are added.

Using "Artifacts" to Foster Learning

Active learning is both product and process based. Ideally, constructing one level of "knowledge product" (or artifact) feeds into the process of attaining yet a higher level of understanding. For example, collected data can be analyzed for patterns and trends, from which the student may be asked to draw cause-and-effect inferences or formulate predictions or generalizations about future behaviors of the elements under study. The very richness of the BioBLAST domain challenged teachers to work through iterative cycles of process fostering a product which then initiated yet another process.

This "spiraling" upward from concrete to abstract was used well by a teacher who started her classes' BioBLAST experience by having each team construct a "quart-jar ecology" (snails, plants, bacteria, and the like). The classes also constructed a 5 by 9 foot human cell and investigated components and relationships. As the course progressed, these "microcosms" became analogs for the more complex and sophisticated macrocosms of Advanced Life Support (ALS) and other controlled ecologies. Additionally, these classes used hands-on experiments (mirroring actual NASA research interests as indicated in the software) to be particularly engaging. They posed questions and formed partnerships with NASA scientists for extending their investigations. For example, students will grow control plantings for an experiment in plant reproduction to be conducted on the space shuttle.

Sustaining the Sense of a "Community" for Scientific Inquiry

Meaningful implementations of collaborative learning require sustaining the intellectual rigor of scientific inquiry while at the same time nurturing the socio-cultural dimensions of group activities that foster respect for individuals and mutual dependencies among students and teacher for learning.

Many of our teacher-leaders insisted upon an open-ended quality for BioBLAST in order to foster collaboration between students and teacher in deciding upon evaluation standards. Discussing possible outcomes and constructing rubrics as a class activity lowers student anxieties and increases motivation. Promoting a constructivist approach to learning, teachers used guided-inductive techniques to help students define issues, determine problems to be solved, and exchange ideas in a series of positive interactions. BioBLAST also helps students establish communities beyond their local situation. Intra-school sharing of data on common experiments marked the "pilot" year. The 1997-1998 implementation has a "newsgroup" feature for students to share both data and reflections. Also, the program contains new opportunities for student to contribute to distributed research and to participate in NASA-sponsored student projects.

In essence, our teacher-leaders recommended that BioBLAST incorporate project-based and inquiry-driven learning, using both content and delivery mechanisms featuring an engaging context from which learners can generate authentic questions for in-depth inquiry. They further suggested that these student-defined investigations be carried out in a community of inquiry where classmates and teachers collaborate to complete complex activities and to produce artifacts available for meaningful assessment. Based on these recommendations, educational technologies (especially advanced media) should be "situated" and should foster collaboration and active learning.

Software that Encourages Students to Become Active Participants in Problem-Based Learning

For this section, I will look specifically at the R-WISE project, and focus on how this "cognitive tool" encourages students to view writing as a critical thinking activity. The past three decades of inquiry into the writing process have yielded a greater understanding of prose composition as a cognitive act. Specifically, Bereiter and Scardamalia (1987) draw upon years of empirical research to extract the notion of "intentional instruction," or explicitly teaching writing as a process of setting goals and achieving those goals through schema-driven strategies and metacognitive awareness.

R-WISE is based on the theories of Bereiter and Scardamalia. As a learning environment, the software provides scaffolding and visual algorithms that gently guide the writer through multi-staged intellectual activities. The software encourages students to practice powerful strategies for composing in a computer-mediated environment that fosters guided-inductive learning and ensures mindful engagement in the task. The entire R-WISE suite is made up of three sets of adaptive workspaces, each mediating the entire writing process but focusing on the strategies and self-regulative awareness characteristic of one of three domains: (1) finding ideas, (2) transforming ideas into prose, and (3) refining both ideas and text into final documents.

Modern pedagogy for teaching composition envisions dramatic changes for the role of the student. However, learners who have grown accustomed to the "traditional" pedagogy which places heavy emphasis on lecture, textbook, and drill may initially flounder when this structure is removed. Certainly, it is unrealistic to think that "little experts" will spontaneously emerge when confronted with an open-ended problem — no matter how intriguing the presentation. Nevertheless, with the guidance of our teacher-leaders, we were able to design software that produced advancements in students' participation in the process and understanding of the content.

Below, I summarize three specific goals that the teacher-leaders identified as crucial to a computer-mediated writing environment.

Improved Strategies for Inquiry

Modern pedagogy emphasize inquiry over lecture and demo. Certainly, the ability to write is engendered through intellectual curiosity coupled with reasoning and patience. R-WISE teachers asked that the embedded pedagogy emphasize improved problem-solving and enhanced critical thinking (asking "why" rather than "how") among students. A second common request was that the software help students to take on larger "chunks" of the process of composing and that students become more self-directed and capable of self-sustaining a high level of effort.

In response to these observations, R-WISE contains a series of "thinking frames" that mediate the transition from "novice" to "expert" behavior in composing. These "cognition amplifiers" ease demands on short-term memory and help to focus the student's attention on strategically important aspects of writing. Additionally, these visual algorithms help the student to self-initiate higher-order processes (metacognition) which the novice writing is unlikely to activate without prompting.

Enhanced Communication and "Publishing" Competencies

Authentic tasks in writing education take students through a "critical path" of asking a question, doing an investigation, answering the question, and communicating the results to others. All teachers mentioned the need for an "invention" workspace in the software suite — both for idea collection and for reflection. Equally important was the ability to share drafts and finished products with classmates. Teachers wanted a vehicle for increased sharing among students which would also enhance students' ability to communicate with peers in collaborative work efforts — for example, in providing commentary and accepting constructive criticism. Most teachers reported that the software suite improved abilities to draw inferences and to develop a synthesis out of multiple sources or perspectives and increased tolerance for uncertainty. Students became more adept at pulling things together and "reporting" for a range of audience, purpose, and forms.

Increased Understanding of Relationship between Information Manipulation and Concept Formation

Understanding the "process" of writing means knowing how to extract higher-order meaning from carefully collected data and objectively recorded observations. Teachers helped to author many quantitative and qualitative activities in R-WISE to encourage students to see the meaningful trends observations and to use this information for such sophisticated cognition as prediction, explanatory generalization, or decision-making.

As a direct result of our teachers' advice, R-WISE was given interfaces that model explicit, strategic intellectual processes so that the fledgling student avoids what Collins and Gentner (1980) have termed "downsliding," or becoming increasingly entangled in lower and lower levels of mental actions, finally concentrating all attention on such things as spelling, grammar, and sentence construction to the exclusion of larger concerns in the process. Additionally, adaptive instructional statements within the context of a workspace mediate transitions from thoughts to symbolic representations. Students are helped with such mature cognitive activities as discerning patterns in bodies of information, decision-making, staged problem solving, analysis, synthesis, and inferencing.

Using Classrooms as Testbeds for Educational Software

The development cycle for BioBLAST and R-WISE emphasized feedback from teachers. I have reported here on the development cycle and initial field-testing of a pre-release versions of two large software projects. At well-defined intervals, "lessons learned" were incorporated into the next release. This overarching commitment to iterative design and formative evaluation has many benefits:

- Integrating Advanced Media into the Curriculum: Software supplements for teaching/learning cannot be treated as "self-driving" or as "stand alone": advanced technologies must gracefully partner with the aims of the teacher and abilities of the students in order to enhance education. Each of the teacher-leaders in both groups is highly adept at fostering both content and concept learning through skillfully orchestrated classroom practices. The creative ways in which each teacher integrated various components of the software into a meaningful "whole" gave the development staff insights in two categories. First, we made valuable observations on the larger pedagogical issues of embedding advanced media in education. Second, we learned much about the more local issues of bundling the tools, activities, and informational support into engaging, day-to-day lessons.
- Accommodating Self-Directed Learners: As valuable as teacher creativity was in using the software, student usage told us much about mediating learning in a problem-based environment. Of the approximately 12,000 students participating in the R-WISE development and the approximately 800 working with BioBLAST, the majority were intrigued by the subject matter and the approach. (Analysis of data — including results from a pre- and post-test have been reported elsewhere). Observation by teachers and from site visits by the development staff point toward increased student engagement.

Developing new approaches to advanced educational applications always involves a risk. These two projects were especially demanding because of the complexity of the domain, the richness of the items included, and the freedom of choice offered both teacher and student in exploring content and performing tasks. However, through the efforts of a multi-talented team, field testing of both R-WISE and BioBLAST demonstrated the fundamental soundness not only of the software but also of the collaborative approach through which they were built.

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