ITR/ACS+EWF:

A Distributed Simulation Infrastructure for a K-12 Inquiry Environment

Proposal To The NSF 99-167 Information Technology Research (ITR)

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In collaboration with

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The Huntington Library, Art Collections and Botanical Gardens
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Section B: Project Summary

We propose to build a scalable, persistent, interactive event simulation framework to support knowledge-building curricula within K-12 education. This is a distributed, entity-based simulation to be used within inquiry-based curricula. Appropriate simulation scenarios would include ecosystems, economies, or governments.

The system uses advanced simulation and information technology methods to create an "*Inquiry Environment*", fostering cooperative interactions and "knowledge co-creation" while students work together to solve curriculum-based problems and challenges. The system is envisioned as a general education tool, not simply a technology demonstration for high-end students. In order to provide the widest possible utilization, the system will be constructed as a distributed server, with WWW-based student access.

The technical basis of the Inquiry Environment is a metacomputing system combining distributed discrete event simulations, informational and operational databases, graphical control interfaces, and visualization. The design and implementation of this system will leverage the substantial expertise of the investigators in these areas. While much of the system can be built from familiar pieces, the education-focused operations model also provides a number of interesting opportunities for new research in computing and metacomputing strategies. For example thread-based simulation architectures will be explored as frameworks more suitable to the uneven usage model of an extended curriculum unit.

The general area of user-directed simulations is viewed as a particular area in which High Performance Computing (HPC) can become a true enabling technology for substantive educational reform. Persistent, interactive, multi-user simulations are becoming increasingly common and useful applications of HPC technologies within the research and defense worlds. The proposed work will explore, develop, and extend these technologies for K-12 education. This is not simply an "application of technology", however, as the objectives and operational environments for an educational simulator differ in many key respects from those of research or industrial applications. An important example here is the emphasis on inquiry and cooperative problem solving strategies rather than mastery of any particular set of facts.

The simulation system we propose cannot have the intended impact on K-12 education if it is constructed as an isolated object or tool. The true potential for HPC cannot be realized without considerations of a larger, three-phase picture in which Computation supports a problem-based Curriculum based on a progressive Cognitive Picture of knowledge and learning.

This proposal relies on strong partnerships in the cognitive science and educational worlds to ensure that the features and capabilities of the technology are matched to objectives within progressive models of knowledge and learning. Leading researchers from the Ontario Institute for Studies in Education at the University of Toronto will provide guidance in the overall cognitive framework. Candidate simulation scenarios and curricula are under investigation with the Huntington Library, Art Collections and Botanical Gardens, a prominent humanities research institution.

The K-12 Simulation Framework developed in this work is regarded as the first step in the larger task of matching HPC capabilities to contemporary cognitive and educational research, enabling substantive advances in learning, as advocated in the National Science Education Standards and the Project 2061 reports.

Section C: Proposal Narrative

This description of the proposed work is divided into four main subsections:

1. **Introduction and Perspective:** Positioning of the K-12 simulation model within a broader learning system, emphasizing the potential for substantive new utilizations of advanced computational methods within a progressive educational context.

2. **Elements of the Simulation Framework:** Overview of the components within the educational metacomputing system. This section notes both the familiar – areas in which the proposal team has substantial experience – and the novel – nuances in the overall framework resulting from its educational objectives.

3. **Research Plan and Partnerships:** The anticipated order in which components and subsystems will be developed. Prototype application developments will involve and extend existing partnerships within the cognitive science and educational communities.

4. **Objectives and Relevance:** A summary of the anticipated outcomes of this research and discussions of these outcomes within the context of NSF and ITR objectives.

1. Introduction and Perspective

> *Technology and media innovation in American schools have been characterized by cyclic fads and a failure to use the sound tools and processes of science to systematically and progressively improve the quality of instruction. As we enter the 21st century, technology has become far too powerful and valuable a learning tool to allow this pattern to repeat.*
>
> **- AAAS Project 2061 Blueprints for Reform [1]**

This proposal concerns the design and implementation of a distributed, scalable event simulation framework for use in K-12 education. The system incorporates several components from recent research in High Performance Computing (HPC) and distributed Simulation and Modeling (SM). The scalable simulation engine at the core of this proposal is supported by information management subsystems, and the full package is similar in many respects to the *Problem Solving Environments* (PSEs) [2] that have been created recently as models for the effective use of HPC assets in the solution of large scientific problems. In order to facilitate student access, the initial implementation model will be WWW based, requiring no special equipment at user sites.

The individual components of the proposed K-12 Simulator are surveyed in the next section. Many of these building blocks are familiar from large-scale scientific and defense applications, including projects in which the proposal investigators have substantial experience. There are, however, interesting technical nuances associated with the learning-focused operations model of an educational system. These research opportunities are noted throughout the discussion.

Before addressing these issues, however, it is important to consider two questions that are perhaps more fundamental:

1. **What is the educational value of the proposed interactive simulation model?**
2. **Why is HPC essential in the implementation?**

These are non-trivial issues, and the temptation exists to attempt answers that are unrealistically based on blind faith in technology itself. One might argue that large, high fidelity simulations are powerful research tools (indeed, the focus of the new NSF 00-26 call for proposals), and that all that is needed is some appropriate “tweakings” of these research codes in order to produce new tools of significant educational utility.

This "technology pulling education" mindset is common, but it is almost always wrong. It is, arguably, at the heart of many of the "cyclic fads and failures" in the Project 2061 lament quoted above. The more reasonable approach is clearly "education pulling technology", but such a statement is meaningless without first defining what "education" is supposed to mean.

As is noted in the National Science Education Standards [3], the Project 2061 reports [1], and throughout contemporary cognitive science research [4], the potential of classroom computing cannot be realized within an education paradigm that is decades out of date. Small steps (e.g., multimedia projects replacing old fashioned scissors and paste creations) are unlikely to lead to the required systemic changes. Substantive technology utilization should, instead, be framed within a broader three-phase approach:

Cognitive: An underlying cognitive science framework of knowledge and learning and the life-long objectives of education.

Curriculum: Specific, focused tasks and knowledge-building exercises, based on the cognitive framework.

Computation: Use of emerging technologies to support and/or enable the knowledge-building activities.

A recent white paper [5] by the PI considers the question of substantive HPC utilization within K-12 education, and the conclusions can be restated within the three-phase context as follows:

Cognitive: Student-directed simulations can serve as "knowledge-building artifacts" within dialogue-based pictures of knowledge and learning (such as the work of Bereiter, Scardamalia, and Wells at OISE/UT [6,7]). Moreover, appropriately designed virtual worlds could extend applications of these concepts by enabling, for example, experiments on social behaviors in large diverse communities.

Curriculum: Knowledge-building activities must be framed in terms of problem-solving situations matched to student abilities - within the "Zone of Proximal Development", to borrow the popular cognitive nomenclature. This implies that typical HPC "big science" simulations are not good choices. Instead, subjects such as sociology, economics and environmental sciences are better arenas for substantive K-12 applications of HPC simulation capabilities.

Computation: Compared with commercial simulation software (e.g., *SimCity*), the advantages available through HPC include:

1. Scalable support for highly interactive, collaborative activities involving many students.
2. Integration of the simulation engine with databases and other information components as a single, coordinated system.

Both of these items are essential from the dialogue-focused perspective of the cognitive framework.

The short answer to the questions posed above can be summarized as:

> *Distributed, interactive simulations offer significant promise as knowledge-building artifacts within inquiry-based K-12 education, provided that the simulator is part of a larger integrated system focused on dialogue and "knowledge co-creation".*

The Problem Solving Environments noted above offer a reasonable, but not quite correct analogy to the goals of this proposal. PSEs are typically focused on solutions to difficult but well-defined large scientific problems, and the environments coordinate big computational assets to address these problems. The focus in the system we propose is not so much on solving problems as on learning/discovering how problems should be defined and then solved. The intent is to build a prototype "Inquiry Environment" – a system aimed more at the development of "Life-Long Learning Skills" [8], and "Attitudes of Expertise" [7] than the mastery of particular facts or practical procedures.

This proposal is concerned almost exclusively with the computational infrastructure of a scalable Inquiry Environment, and the proposed work involves extending and adapting HPC and metacomputing techniques as an enabling tool for K-12 learning. This is innovative technology utilization, as suggested in both the National Science Education Standards and in the Project 2061 reports. However, within the Cognitive-Curriculum-Computation framework described above, treatment of the computational component in isolation is a rather fruitless task. Connections between this work and ongoing activities to structure the full Inquiry Environment are noted in Section 3, including ongoing work on prototype application definition and planning.

2. Elements of the Simulation Framework

This section explores the objects and procedures to be incorporated into the K-12 simulator framework. Many of the elements are derived from existing large-scale scientific and defense simulations and metacomputing applications. The proposed work leverages substantial prior research by the investigators. However, there are a number of instances in which the educational objectives of this project require interesting, challenging excursions from standard, research-style implementations. These additional research opportunities are noted in the discussions below.

2.1 Basic Entity-Based Paradigm

Adopting standard simulation practices, individual entities will be instanced as objects and interactions will be message driven. A generic schematic for this approach is shown in Fig. (1).

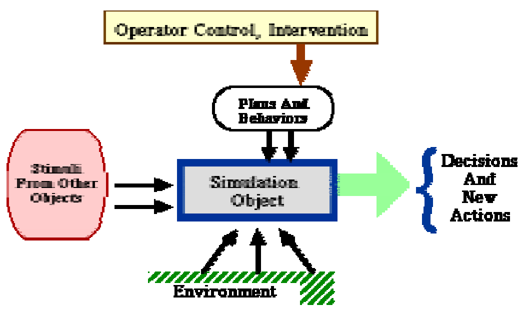

Figure 1: Schematic of the basic simulation paradigm.

Entities are implemented as objects (in the C++ or Java sense), and the update cycle for such objects can typically be divided into three phases:

1. The object collects stimuli (messages) from suitably nearby objects and from the environment.
2. Based on its current state, the nature of the new inputs, and its standard rule-sets ("behaviors") the object effects changes in its current state.
3. The object issues a number of messages to make its decisions and actions known to other objects within the simulation, possibly altering its environment in the process.

As one example from the literature, Epstien and Axtell [9] use this basic, object-oriented formalism to explore the behaviors of systems populated by large numbers of similar or identical entities. The essential extension in this proposal is the introduction of significant user control of individual entities by way of changes in object parameters or behavior rule sets. This generalizes the multi-user control capabilities of ModSAF [10], a large-scale DoD simulation program.

Significant student-initiated control capabilities are mandatory for the cognitive and educational objectives of the K-12 Simulator.

A number of existing simulation models can be considered within the paradigm of Fig. (1), with many of the differences ascribable to the modeled complexities of individual entities. Determination of appropriate entity fidelity for K-12 applications is one of the more significant research questions to be explored early in this project. Within the restricted scope of the simulator design, flexibility and generality are essential, including support for widely varying entity complexities within a single simulation. For example, each student is a class might manage a naïve “idealist” battling against a big government behemoth controlled by the teacher.

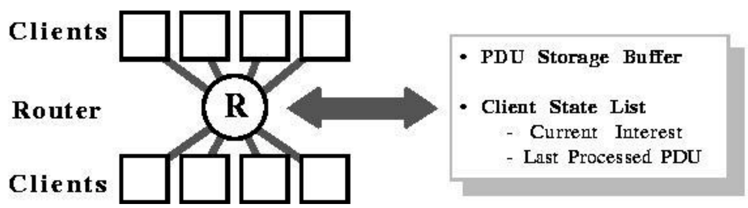

Figure **2**: Schematic, Router-Based Messaging Mechanism.

In scalable, distributed simulations, messages must be exchanged among entities instanced on distinct processors. The proposed mechanism for this messaging will be based on the router procedures developed by the PI for the SF Express [11] scalable implementation of ModSAF. This scheme uses intelligent store-and-forward router processes as illustrated schematically in Fig. (2), where the term “PDU” (Protocol Data Unit) indicates a generic ModSAF message. A hierarchical communications architecture based on Fig. (2) was the communications framework for the distributed SF Express simulation with 100K vehicles, run on a multi-platform metacomputer that spanned seven time zones. The communications scheme implemented for this project will, in fact, be considerably cleaner and simpler, since the legacy code constraints of ModSAF PDUs can be avoided from the outset.

2.2 Environment Modeling

There are many available options for modeling the environment in which the simulated entities interact, ranging from the simple cell-based procedures used in *Sugarscape* [9] and *StarLogo* [12] to the very dynamic terrain and weather modeling found in the most recent descendants of ModSAF. This project will exploit experience from the SF Express project, with a number of extensions and modifications to support the inquiry-based character of the K-12 simulator.

Consider, for example, a K-12 ecology-focused simulation. The environment in such circumstances could be implemented through several straightforward pieces:

1. A grid-based “playing field”, providing a structure for positioning entities, a description of static properties (e.g., ocean versus land) and possibly some information on dynamic assets.

2. Some number of environmental entities instanced as actual objects within the simulation framework. For example, a problem-solving simulation might require teams of students to cut and collect trees in order to build shelters, bridges, etc.

3. Significant operator intervention capabilities, allowing teachers to modify the environment to further educational objectives. These could include both refinements of environmental parameters and the introduction of occasional catastrophic events.

The position grid in the first item would also support a number of geometry-related services, such as proximity detection and route planning. The use of a mixed representation of the environment in terms of both a position grid and “semi-simulated” objects will support a wide range of plausible K-12 applications.

However, the geometry/geography-based implementation outlined above is likely too restrictive for the full class of simulations of interest, such as economies. The familiar terrain-based decompositions must be generalized, and alternatives based on more abstract interpretations of concepts like “fixed features”, “expendable resources”, “intervention”, and “proximity” will be needed.

2.3 Time Management and Overall Operations Concept

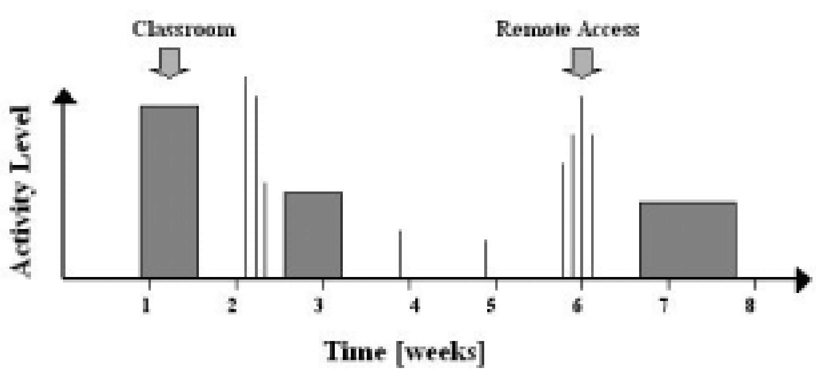

Figure 3: Schematic Simulator Usage Timeline

On first glance, the time-related requirements for the K-12 simulator are fairly benign, with no need for anything like the 100 msec update time scales of ModSAF. A simple, lock-step time management protocol would seem adequate. The router processes of Fig. (2) provide a natural mechanism for both time control and time synchronization across multiple processes.

In reality, the synchronization and operations issues associated with a K-12 simulator involve a number of unique challenges related to the anticipated, highly non-uniform usage model.

Figure 3 illustrates a plausible time history for student interactions with the simulation system. The grey boxes indicate periods of focused classroom activities, while the clusters of lines indicate times in which student interactions are largely limited to occasional observations ("data taking"). The extended periods of minimal interactions allow the system to "evolve" according to behaviors and objectives set by the students.

The activity map in Fig. (3) is not an unreasonable picture for a K-12 application – in fact, it rather closely resembles interaction histories for a hands-on unit on plants. During the gaps while the plants grow, classroom activities might focus on expanding basic information, so that the students are better prepared to use new data available once the plants have matured.

The time-management requirements of a K-12 simulator are, in fact, quite different from existing large scale scientific and military simulators, and some of these differences are inherently interesting from computing and metacomputing perspectives. This is an opportunity/motivation for additional research on data-driven, thread-based simulation procedures.

2.4 Database Components

Significant data management capabilities are clearly required within the knowledge-building objectives of the K-12 Simulator. There are several different classes of data and database activities that would be important in the overall system:

1. **Operational:** At a minimum this includes periodic checkpointing of the system state to provide replay and restart capabilities. More interestingly, an Object Oriented Database Management System (ODBMS) provides a plausible alternative to the ModSAF-like overall operations approach of the previous section.

2. **Informational:** Users need access to variety of system descriptions, such as states of individual entities or portions of the environment. Ideally, the same interface would be used to provide access to static background material, as might be prepared and provided by teachers.

3. **Cognitive Analysis:** One promising approach to learning assessment uses associative neural networks to identify patterns in student problem solving strategies [13]. The K-12 system could easily be extended to record action histories for individual students. Initially, these data would be inputs to off-line cluster analyses, and ultimately might be used as part of an integrated, real-time assessment system within the context of the particular K-12 application.

4. **Discourse:** Within an overall knowledge-creation cognitive framework, interactive, searchable dialogue tools are seen as essential components of an overall learning system. The CSILE and Knowledge Forum [14] packages are canonical examples, and incorporation of these systems (or approximate clones) is an important part of the overall K-12 system.

The use of ODBMS to oversee system operations is an interesting alternative to the more conventional mechanism suggested in the previous subsection. In this approach, simulation entities exist as objects within the database and there are two classes of ODBMS clients:

1. End users, participating in the simulation.
2. System managers, running management tasks.

On connection to the ODBMS, a client retrieves the object schema and current simulation state, and begins interacting with the simulation. Each interaction is time-stamped and recorded as a persistent object in its own right. Once the client has finished interacting with the system, the ODBMS sessions is closed and the client detaches.

ODBMS-based simulation frameworks will be explored as alternatives to the more standard approaches of Section 2.2 as part of this proposal.

2.5 Visualization and User Interfaces

Large-scale simulations provide enormous opportunities for visual interactions with the users. In the overall operations picture noted in Section 1, student interactions with the K-12 simulator will be primarily WWW-based, so that effective, engaging graphical interfaces are extremely important.

Several different categories of displays and graphical interfaces would be needed within a basic Inquiry Environment, including:

Information/State Displays: Representations of the current simulation state and properties of the individual entities at levels required to support problem-solving activities by the students.

Entity Control Panels: Graphical tools to adjust behavior models of individually controlled entities.

Information Access: Simple query tools and/or integrated access to the information database and discourse system discussed in Section 2.4

Beyond these control-directed components, some level of animation would also seem worthwhile – for example, visual replays of system evolution to help identify the actual consequences of prior actions by the students. The best form for such displays remains open to debate, however. On cognitive/educational grounds, the boundary between "engaging" and "distracting" graphics is far from clear (and, consequently, an interesting ancillary issue that might be explored within the basic K-12 simulator framework). On a more practical note, the initial implementation model of WWW-based student access provides operational constraints on the visualization components.

2.6 Advanced Concepts

A substantial, student-directed simulation framework can be constructed from the items listed in the preceding subsections. The resulting system would have more than enough capabilities and flexibilities to serve as a true "knowledge building artifact", in the sense described in Ref. [6]. The system also provides a framework for experimentation with a number of more advanced concepts.

<u>Student-Directed Object Definitions</u>

Students must have substantial freedom in altering behaviors of the entities they control. For simplicity, the initial implementation will follow the largely parametric approach used, e.g., in ModSAF in which

1. The state of an entity is defined by a number of user-adjustable parameters and nominal behavior rules.
2. Student interventions alter the behavior rules.

However, student flexibility in this approach is limited to that incorporated into the original object models, and truly innovative actions are often not supported.

There is considerable ongoing research into this issue, such as the *AgentSheets* [15] approach developed at Center for LifeLong Learning and Design at the University of Colorado. Options such as *AgentSheets* will be explored as part of this research.

<u>True Metacomputing</u>

The distributed simulation engine and databases discussed so far form only part of a true metacomputing system for K-12 applications. Members of the team for this proposal have worked with the Globus [16] group in the past, and there are a number of aspects from Globus (such as resource allocation and scheduling), which should be incorporated into mature versions of the K-12 simulator. For example, the system could support significant "what if" capabilities by way of student-initiated, CPU-intensive Monte Carlo simulations of possible future states.

As noted above, the uneven timelines for student interactions provide an ideal opportunity for research on simulation frameworks other than the standard time-driven paradigm. In a more data-driven paradigm, entities would exist as database objects, and "interactions" would spawn processes executed on a thread-based computational engine.

Assessments and Explorations Of Expertise

The K-12 simulator provides an opportunity for "measuring" cognitive processes, such as problem solving strategies. The work by Stevens and collaborators in Ref. [13] has demonstrated that common problem solving patterns can be inferred from, effectively, data mining analyses of activity records. This approach will be explored as an additional capability within the K-12 simulator. The database components would accumulate basic data on student actions, and the analyses procedures of Ref. [13] could be supported in real-time within the distributed computation engine. The information/insights determined in this fashion would have value both for learning assessments and for basic cognitive research.

3. Research Plan and Partnerships

The components described in the preceding section are building blocks for a scalable, knowledge-building system – a novel, substantive application of HPC technology to K-12 education, along the lines sought in Refs. [1,3]. Construction of these components will leverage the experience of the proposal team in the areas of distributed simulations, databases, and metacomputing. The more fundamental challenge in the research program comes in ensuring that the whole built from these technical parts remains an enabling tool for learning, and not merely a "technology insertion".

Software and system development will occur in a number of phases:

1. **Basic Simulation Framework**: A prototype system will be built combining the basic entity picture of Fig. (1) with the router-based messaging scheme of Fig. (2) and simple time control managed by the router. This will provide enough structure to enable experiments with a number of key components:

    - Generic object templates and models for "behaviors".
    - Message content and structure.
    - Environment representations and interaction mechanisms.

2. **Object Management Database**: A distributed database will be added to the system to manage state characterization data. This allows development of:

    - System store/restore functionality.
    - Basic displays for assessment of simulation and entity status.
    - Initial user control/intervention capabilities.

3. **Prototype Application Development**: Once the initial object management components are in place it will be possible to begin significant explorations of educational prototypes.

4. **Metacomputing Extensions**: Investigations of system reliability, integrated operations, and resource allocation as well incorporation of the information and discourse database components from Section 2.4.

5. **Advanced Concepts**: The notion of thread-based, database-managed alternatives to time-driven simulations will be explored early in the research program. Other aspects (in particular, mechanisms for enhanced student control of entity behaviors) will be explored once the overall operations model is in place.

While concurrent work in these areas is plausible/likely, the initial emphasis will be on the first two items. It is important that a skeletal end-to-end system be available for education-directed experiments as soon as possible. Once a prototype system is available, the five areas will be revisited within a standard, spiral-style software development approach, adding and exploring additional features in concert with needs discovered during the education-based experiments.

The specific intent of this proposal is the development of the computational framework for a knowledge building system, and the software development plan sketched above will indeed produce such a product. However, as noted above, a computational system without both a cognitive framework and a curriculum focus is unlikely to have any significant impact on education. While careful explorations of cognitive and curriculum issues are beyond the specific scope of this proposal, these issues cannot be ignored as the technical nuts and bolts are put into place.

In order to provide and maintain a proper, broader perspective during the construction of the K-12 Simulator, strong partnerships with cognitive scientists and educators will play an important part in this proposal. These include:

Ontario Institute for Studies in Education, University of Toronto: OISE/UT is Canada's premier institution for educational research, with particular emphasis on the "establishment of a learning society". Marlene Scardamalia, Carl Bereiter, and Gordon Wells are recognized experts in cognitive research and applied learning methods. Their input has been important in refining the existing K-12 simulator concept. They will continue to guide the cognitive framing of the overall project in general, and will assist in the particular task of incorporating the discourse database component.

The Huntington Library, Art Collections and Botanical Gardens: The Huntington is a world-renowned center for studies in the Humanities (with significant historical ties to Caltech). The new "34-th Parallel" project of the Botanical Gardens is an effort to involve students from schools at this latitude around the world, exchanging climate and plant data. The Huntington Botanical Gardens represent one of the nations richest botanical resources, and efforts have begun to create a substantial Botanical Research and Education Complex. The K-12 simulator of this proposal is under consideration as the technical framework for the 34-th Parallel project.

The CORAL Project: CORAL (Communities Organizing Resources to Advance Learning) is a major new initiative of the John Irvine Foundation, and the Pasadena was selected as the pilot participant in his program in November 1999. This is substantial, multi-year effort to create significant, technology-based after school programs and activities with particular emphasis on under-served neighborhoods. The simulation model described in this proposal is under consideration as one component of the (still undecided) CORAL technical framework, possibly in conjunction with the “34-th Parallel” project.

NuMedeon: NuMedeon, an Internet start-up company, has affiliations with Caltech and CAPSI. Their first site, Whyville.net, provides inquiry-based activities for young learners in grades 5-10. The site supports science education, other inquiry-based education, and learner interaction in a virtual community. The company has displayed success in programming client interfaces using Java, appropriate for children to use, and server software using C and C++, which handle virtual community communication and shared data structures.

Ongoing interactions with OISE/UT will help ensure the “technology serving education” thrust of this project. Both the 34-th Parallel and CORAL projects provide attractive proving grounds for the overall Cognitive-Curriculum-Computing picture in that:

1. The underlying educational concepts are “large scale”, in terms of the number of participating students, the extended durations of the interactions, and the potentially large amount of interesting support data.
2. Both projects are structured as persistent, largely extra-curricular activities. This separation from the (unfortunate) constraints of state curriculum guidelines will provide significant freedom in exploring innovative practices and educational reforms.

The Caltech Pre-College Science Initiative (CAPSI) project is another significant local resource with considerable expertise in K-12 outreach. The NuMedeon group has substantial expertise in educational user interfaces and will provide assistance in that phase of this project.

Letters of Interest from OISE/UT, The Huntington, and NuMedeon are included as part of this proposal package.

In addition to these major partnerships, it is anticipated that the working relationships with local school districts and educators noted in Ref. [5] will continue.

4. Objectives and Relevance

The primary technical results from this work will involve the scalable K-12 simulation framework itself. The creation of a metacomputing system directed towards the fostering of learning skills (rather than scientific problem solving) does lead to a number of interesting research opportunities, but no real obstacles. Given the experience of the proposal team, the technical work done under this proposal can be expected to result in a flexible, scalable system capable of supporting a wide variety of student-directed activities.

The challenge in this – or any other K-12 application of High Performance Computing – comes in ensuring that the "technology solution" actually addresses a real educational issue. Given experience with scientific simulations and Problem Solving Environments, it is easy to find many elements of "promisingness" in the notions of scalable integrated systems and student-directed simulations. It is quite another matter to identify the manner in which these tools should be used to enable significant advances in learning.

The broader educational issues associated with the K-12 simulation concept are difficult. Within the context of K-12 science education, the National Science Education Standards notes that:

> *Implementing the standards will require major changes in much of this country's science education. The Standards rest on the premise that science is an active process.*

This "active process" perspective is not unique to science education – it is central to most contemporary cognitive research. Learning happens in doing "interesting stuff" in the context of authentic, complex problems. <u>Real</u> learning requires active collaboration.

The bold new technology utilizations urged within both the National Science Education Standards and the Project 2061 reports cannot be achieved by a team of computational scientists, no matter how interesting and powerful the underlying computational tools may be. The partnerships with OISE/UT noted in the previous section are an absolutely critical element of this proposal. Development of the K-12 Simulator "laboratory" is the first, basic step in a broader program of research and development, matching the capabilities of HPC to collaborative knowledge building.

We suggest that this proposal is a concrete first step towards a new, progressive match of advanced computing technology and fundamental learning objectives, as envisioned in both the National Science Education Standards and in Project 2061. This is fundamental research that directly addresses a number of elements of the general NSF merit review criteria:

- This is a significant new direction in the matching of computational capabilities to cognitive/learning objectives.
- The proposal team and partners are highly qualified.
- This project is undertaken with the intent of exploring/defining new, substantive changes in education.
- The proof-of-concept implementations noted above are, by design, aimed towards large, diverse student populations.

The proposed work addresses a number of specific issues/objectives noted in the ITR program solicitation announcement:

- This is fundamental research on the utilization of advanced information technology within education.

- The metacomputing system concept outlined above touches on a number of issues noted in the ITR announcement:
  1. Scalable, reliable software.
  2. Effective user interfaces and data display capabilities.
  3. Integration and utilization of static and dynamic databases.

- The creation of an integrated system using these components to provide a real advance in education and learning methodologies would certainly touch on the social implications of IT.

Within the specified categories of the ITR Program Solicitation, the work outlined in this proposal fits most comfortably within the Advanced Computational Science section. This system we propose to construct is, in essence, a new type of Problem Solving Environment, albeit with interesting additional technical wrinkles. The technical work is very strongly coupled with research and researchers in the educational and cognitive science fields, and is very much focused at fundamental problems in these areas.

The larger picture objectives of this work are focused on exploring and defining appropriate substantive utilizations of HPC and IT technology within progressive models (research and applied) of education and learning. This would appear to be slightly broader in scope than the IT literacy focus of the Information Technology Education and Workforce section of the ITR solicitation, but the strong educational focus of this proposal suggests that ITEW should be included as a secondary category.

Section D: References

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