INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS

Submit only ONE copy of this form with your proposal. Attach it on top of the cover page of the copy of your proposal that bears the original signatures. Leave the back of the page blank. *Do not include this form with any of the other copies of your proposal, as this may compromise the confidentiality of the information.*

Please check the appropriate answers to each question for all principal investigator(s)/project director(s) listed on the cover page, using the same order in which they were listed there:

	Principal Investigator/ Project Director	First Additional PI/PD	Second Additional PI/PD	Third Additional PI/PD	Fourth Additional PI/PD
1. Is this person					
Female	☐	☐	☐	☐	☐
Male	☒	☒	☒	☒	☐
2. Is this person a					
U.S. Citizen	☒	☒	☒	☐	☐
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3. Which one of these categories best describes this person's ethnic/racial status? (If more than one category applies, use the category that most closely reflects the person's recognition in the community.)					
American Indian or Alaskan Native	☐	☐	☐	☐	☐
Asian	☐	☐	☐	☐	☐
Black, not of Hispanic Origin	☐	☐	☐	☐	☐
Hispanic	☐	☐	☐	☐	☐
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4. Does this person have a disability* which limits a major life activity?					
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No	☒	☒	☒	☒	☐
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Required: Check here if this person is currently serving (or has previously served) as PI, Co-PI or PD on any Federally funded project.	☒	☒	☒	☒	☐

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the orignal peoples of Hawaii; the U.S. Pacific territories of Guam, American Samoa, and the Northern Marinas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.

*Disabled: A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of the proposed principal investigators/ project directors and co-principal investigators. To gather the information needed for this important task, you should submit a single copy of this form with each proposal; however, submission of the requested information is not mandatory and is not a precondition of award. Any individual not wishing to submit the information should check the box provided for this purpose. (The exception is information about previous Federal support, the last question above.)

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S)
(Indicate the most specific unit known, i.e. program, division, etc.)

LEARNING & INTELLIGENT SYSTEMS

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter GPG, NSF 95-27

NSF 97-18 **05/15/97**

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NSF PROPOSAL NUMBER

9720351

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376000511

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☐ A RENEWAL OR
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NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

University of Illinois at Chicago

AWARDEE ORGANIZATION CODE (IF KNOWN)

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ADDRESS OF AWARDEE ORGANIZATION, INCLUDING ZIP CODE

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Chicago, IL. 60607

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(See GPG II.D.1 For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Deep Learning and Visualization Technologies**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE
$ **1,468,648**	**36** months	**10/01/97**

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG 1.A.3)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.D.1)
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☐ VERTEBRATE ANIMALS (GPG II.D.12) IACUC App. Date
☒ HUMAN SUBJECTS (GPG II.D.12)
Exemption Subsection or IRB App. Date **03/13/97**
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES
☐ FACILITATION FOR SCIENTISTS/ENGINEERS WITH DISABILITIES (GPG V.G.)
☐ RESEARCH OPPORTUNITY AWARD (GPG V.H)

PI/PD DEPARTMENT
Software Technologies Research Center

PI/PD FAX NUMBER
312-413-7585

PI/PD POSTAL ADDRESS
851 S. Morgan Street, Room 1120 SEO
M/C 154
Chicago, IL 606077053
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CO-PI/PD				

NOTE: THE FULLY SIGNED CERTIFICATION PAGE MUST BE SUBMITTED IMMEDIATELY FOLLOWING THIS COVER SHEET.

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE NSF INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Date
PI/PD **Thomas A DeFanti**		
Co-PI/PD **Andrew E Johnson**		
Co-PI/PD **Thomas G Moher**		
Co-PI/PD **Stellan Ohlsson**		
Co-PI/PD		

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding Federal debt status, debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 95-27. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debt and Debarment Certifications

(If answer "yes" to either, please provide explanation.)

Is the organization delinquent on any Federal debt? Yes ☐ No ☒

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure Form to Report Lobbying,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) **Mi Ja Kim**		**05/15/97**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
312-996-4993	**u27279@uicvm.uic.edu**	**312-996-9005**

PROJECT SUMMARY

See GPG Section II.D.4 for guidance on contents.

The ability to grow and adapt is central to intelligence, in both natural and artificial systems. The learning sciences are moving towards a deeper understanding of the laws that govern cognitive change. Theoretical development is most advanced with respect to learning propositional knowledge by reading and acquiring skills by practicing. Conceptual change—the acquisition of new ideas—is less well understood. In the proposed work, we aim to advance the study of conceptual change by focusing on *deep learning*, the acquisition of ideas that are more fundamental than the learner's prior ideas about the relevant domain.

Deep learning is intrinsically connected with the human ability to design, make and share symbols. Symbol systems (language, drawing, algebraic notation, musical score, chemical formulas, sculpture, etc.) have enabled artistic, practical and scientific achievements far beyond the level of cognitive growth that is possible for an unaided mind. A symbol system requires a symbol formation technology for creating and sharing symbols; paper-and-pencil and photography have until recently been the most ubiquitous examples. However, computer technology provides us with almost unlimited capacity to invent and use novel symbol systems. In particular, it enables a range of advanced *visualization technologies*, with three-dimensional (3D) representations and virtual reality (VR) systems the most dramatic examples.

In the proposed work, we aim for a deeper understanding of the relation between deep learning and advanced visualization technology. We propose to build on past and current work at the Electronic Visualization Laboratory (EVL) to develop a series of 3D/VR representations ('worlds') within which deep conceptual learning can take place. For each world, we plan to investigate its power to support deep learning in both individuals and collaborative groups, explore the novel representational and interaction techniques possible within 3D/VR environments, and work with practitioners to develop effective and efficient ways to deploy these technologies in schools.

The significance of the proposed work resides in (a) the focus on deep learning, (b) our selectionist framework and the strategy for supporting learning that we derive from that framework, (c) our plan to employ an existing advanced technology capability in the service of that strategy, (d) our proposals for how to augment that capability, and (e) the goal of developing models for injecting the technology into educational and other socially important contexts.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

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A	Project Summary (NSF Form 1358 (not to exceed 1 page))	1	
B	Table of Contents (NSF Form 1359)	1	
C	Project Description (NSF Form 1360) (including Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	18	
D	References Cited (NSF Form 1361)	3	
E	Biographical Sketches (NSF Form 1362) (Not to exceed 2 pages each)	12	
F	Summary Budget (NSF Form 1030, including up to 3 pages of budget justification/ explanation)	7	
G	Current and Pending Support (NSF Form 1239)	3	
H	Facilities, Equipment and Other Resources (NSF Form 1363)	1	
I	Special Information/Supplementary Documentation		
J	Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		
	Appendix Items:		

*Proposers may select any numbering mechanism for the proposal. Complete both columns only if the proposal is numbered consecutively.

PROJECT DESCRIPTION

See GPG Section II.D.4 for guidance on contents.

PURPOSE AND ORIENTATION

The ability to grow and adapt is central to intelligence, in both natural and artificial systems. The learning sciences are moving towards a deeper understanding of the laws that govern cognitive change (Chipman & Meryrowitz, 1993; Ram & Leake, 1995). Theoretical development is most advanced with respect to learning propositional knowledge by reading (Kintsch, 1988, 1994; Rayner & Pollatsek, 1989) and acquiring skills by practicing (Anderson, 1993; Ericsson, Krampe, & Tesch-Romer, 1993; Ohlsson, 1996; Proctor & Dutta, 1995). Conceptual change—the acquisition of new ideas—is less well understood (Chi, 1992; Ohlsson & Lehtinen, in press; Thagard, 1992; Vosniadou & Brewer, 1994). In the proposed work, we aim to advance the study of conceptual change by focusing on *deep learning*, the acquisition of ideas that are more fundamental than the learner's prior ideas about the relevant domain.

Deep learning is intrinsically connected with the human ability to design, make and share symbols. Symbol systems (language, drawing, algebraic notation, musical score, chemical formulas, sculpture, etc.) have enabled artistic, practical and scientific achievements far beyond the level of cognitive growth that is possible for an unaided mind (Donald, 1991; Gardner, 1994; Goodman, 1976; Werner & Kaplan, 1963). A symbol system requires a symbol formation technology for creating and sharing symbols; paper-and-pencil and photography have until recently been the most ubiquitous examples. However, computer technology provides us with almost unlimited capacity to invent and use novel symbol systems. In particular, it enables a range of advanced *visualization technologies*, with three-dimensional (3D) representations and virtual reality (VR) systems the most dramatic examples.

In the proposed work, we aim for a deeper understanding of the relation between deep learning and advanced visualization technology. We propose to build on past and current work at the Electronic Visualization Laboratory (EVL) to develop a series of 3D/VR representations ('worlds') within which deep conceptual learning can take place. For each world, we plan to investigate its power to support deep learning in both individuals and collaborative groups, explore the novel representational and interaction techniques possible within 3D/VR environments, and work with practitioners to develop effective and efficient ways to deploy these technologies in schools.

Over the past five years, EVL has developed a successful operational model which has resulted in the invention of highly novel VR technologies (CAVE, ImmersaDesk, and Infinity Wall) and high-bandwidth networking and database technologies (Cruz-Niera, et. al. 1993). We have served as a national testbed for researchers in scientific visualization, providing direct on-site and remote support and training for a broad range of collaborators. We have initiated in-house research applications, environments, and tools which have advanced knowledge in the content domains. And we have effectively disseminated our results to both industry, government, and academe; there are now 12 CAVES and 22 ImmersaDesks in active operation around the world. An obvious advantage that we hold is that this infrastructure—technological and human—is already in place, and growing rapidly. This will allow us to concentrate funding in support of educational research projects rather than lab-building efforts.

Put simply, the plan for our Center is to do for VR and education what EVL has done for VR and scientific visualization, by providing:

- an advanced, experimental equipment and systems base (two CAVES, four ImmersaDesks, an Infinity Wall, OC3 ATM connectivity to Argonne National Laboratory and NCSA), and strong working relationships with systems and software vendors,
- a demonstrated orientation toward the continuous formation and support of external, multidisciplinary collaborations,
- a strong program of internally generated research projects by nationally recognized researchers,
- an experienced, professional staff providing technical and research support,
- an aggressive dissemination program based major efforts at presentation at national conferences, residency of visiting researchers and practitioners, and center-sponsored events,
- a specialized, cross-disciplinary program of graduate training, with special emphasis on the development of skill sets enabling students to serve as liaisons among researchers, practitioners, and technologists, and
- an ongoing consolidation program of tool and standards development as an outcome of the development of prototype experimental projects.

Section 1 describes our approach to deep learning and develops the link to advanced visualization technology. It ends with an overview of our research questions. Section 2 lays out a sequence of 3D/VR 'worlds', and outlines the program of research that we envision vis-a-vis each. In Section 3, we sketch a model for how to bring advanced visualization technology to education. Section 4 summarizes the significance of the project.

1. DEEP LEARNING

The learning sciences have approached cognitive change from many directions. Researchers in cognitive psychology (Chipman & Meyrowitz, 1993; Schank, 1986; Siegler, 1996), educational research (Bruer, 1994), artificial intelligence (Langley, 1996; Ram & Leake, 1995), linguistics (Jackendoff, 1994; Pinker, 1989), philosophy of science (Giere, 1992; Thagard, 1992), cognitive neuroscience (Churchland, 1995; Squire, 1987) and cognitive anthropology (Hutchins, 1995; Shore, 1996) and other areas have asked interesting questions about learning and carried out worthwhile investigations. One distinctive feature of the present approach is a focus on a particular type of learning target.

What is Worth Learning?

Underneath the extensive systems of domain-specific knowledge (facts, skills) that a person brings to bear on problems and situations, there are organizing concepts—fundamental ideas—that influence how both direct experience and discourse within that domain are conceptualized. Such *deep ideas* are most visible in the natural sciences, because of the greater degree of articulation, externalization and canonicalization of knowledge in those fields. Examples of deep ideas in science include inertia, conservation of energy, natural selection, dynamic equilibrium, feedback, self-organization, and so on. Deep ideas form the axiomatic core of entire systems of knowledge, and they influence how knowledge within those systems is acquired and used.

Although deep ideas are most visible and most clearly articulated in the natural sciences, we do not mean to imply that they are unimportant elsewhere. Social scientists have uncovered organizing ideas that guide and inform how people think about social and political processes: the so-called Just World Belief is an example (Furnham, 1988). Free market, majority vote, representative democracy and due process are among the deep ideas that are needed for a full understanding of important social, economic and political processes. We take the existence of deep ideas as a general characteristic of human knowledge and possibly of knowledge-based systems generally.

What is worth learning in a constantly changing world where the totality of knowledge has long since expanded beyond what a person can master during a lifetime? We contend that intelligence and adaptability are anchored in a core repertoire of deep, often abstract ideas that guide and facilitate the construction of more specific conceptualizations within particular domains (Ohlsson, 1993). We turn next to the question of how such ideas are acquired.

Idea Acquisition and the Learning Paradox

The acquisition of deep ideas—deep learning—might well follow laws other than the learning of either propositions or skills (Ohlsson, 1995a). Briefly put, the acquisition of deep ideas moves from the specific to the abstract, while skill acquisition moves from general methods to increasingly domain-specific expertise. Deep learning moves from intuitive notions to higher levels of awareness and explicitness; skill learning, in contrast, moves from effortful and deliberate attempts to perform the practice task towards the effortless and almost unconscious performance that is characteristic of automaticity. The vehicle for skill acquisition is deliberate practice (Ericsson, Krampe & Tesch-Romer, 1993); the vehicle of deep learning is reflective exploration. We cannot assume that cognitive mechanisms developed to account for other types of learning will also suffice to explain deep conceptual learning.

The acquisition of deep ideas encounters a peculiar paradox. The ideas that underpin advanced understanding in different fields are typically more fundamental than the ideas a novice learner might bring into the field from prior experience (Confrey, 1990; McCloskey, 1983; Perkins & Simmons, 1988). This fact helps explain the puzzling observation that although many deep ideas can be stated in less than a page of text, systematic attempts to teach them nevertheless fail with alarming frequency (Bruer, 1994). Educational researchers, particularly in the fields of science and mathematics, have found over and over again that seemingly thoughtful programs for teaching deep ideas can be unsuccessful (e.g., Resnick & Omanson, 1987).

This outcome can be understood in terms of one of the central principles of the learning sciences: *Existing knowledge is the main tool for understanding new experience or new discourse*. In other words, both direct experience and discourse (oral or written) is understood by being analyzed in terms of, or assimilated to, existing

knowledge structures. For example, a fairy tale is understood by being subsumed under the reader's existing schema or story grammar for fairy tales. This subsumption process operates without difficulty when experience or discourse is congruent with existing organizing ideas. A narrative of a baseball game, for example, is completely comprehensible to someone who already knows the nature, structure and character of the game. A newspaper story does not attempt to change the reader's conceptual understanding of the game, just to communicate particular information consistent with it. Learning from instructional discourse with a similarly constrained goal is also relatively unproblematic.

However, when either experience or discourse (instructional or otherwise) attempts to communicate a deep idea that is both different from, and more fundamental than, the learner's existing ideas, a paradox occurs. Although the intent behind the discourse is to replace the learner's existing ideas, those existing ideas are the learner's only tools by which to acquire the new idea (DiSessa, 1988, 1993). Research in the cognitive sciences has documented that the typical outcome of this fact is distortion: the novel idea is misunderstood in the process of—and as a byproduct of—being assimilated to prior knowledge.

A simple and compelling example of this effect has been documented by Nussbaum (1985) and by Vosniadou (1994) and Vosniadou and Brewer (1994): Young children tend to believe that the Earth is flat. One's concept of the shape of the Earth has profound consequences for one's interpretation of both experience and discourse, so the shift from a flat Earth to a spherical Earth view counts, at an elementary level, as deep learning in our framework. Empirical studies have demonstrated that if children are told that the Earth is round, they often react to the novel information by constructing a mental model of the Earth as a pancake, flat yet round. The intended message is distorted in the process of assimilation to mean that the Earth is circular (rather than spherical).

Although simple (to adults), we suggest that the flat Earth/round Earth case is prototypical of deep conceptual learning that exemplifies the essential features of the learning paradox at any age level: Both experience and discourse that attempt to communicate ideas that are deeper or more fundamental than the ideas the learner already has tends to be distorted in the comprehension process, because those prior ideas are the main tools for understanding. This is the learning paradox (Bereiter, 1985). Support for deep learning must overcome this paradox.

Circumventing the Learning Paradox

If the learning paradox is real, how is anything new ever learned? Our approach to this question is founded on a distinction between transformational and selectionist explanations of cognitive change. A *transformational* account assumes that new knowledge is created via operations on prior knowledge. Prior knowledge serves as raw material, and new knowledge is the result of generalization, specialization or some other type of cognitive operation, applied to that raw material.

One example of a transformational approach is the classical induction hypothesis: knowledge is created by extracting commonalities across a set of exemplars or instances. Inductive approaches to learning (sometimes referred to as similarity-based approaches) encounter several unsolved problems, including how to handle exceptions and disjunctions (Angluin & Smith, 1983). Another example of a transformational view is the attempt to conceptualize science learning as a form of belief revision, an approach that provides students with evidence to the effect that their intuitive beliefs (sometimes called misconceptions) are false, and that they need to replace them with more accurate beliefs (Hewson & Hewson, 1984; Posner, Strike, Hewson & Gertzog, 1982). The belief revision approach has so far failed to live up to the claims initially made by its advocates (Smith, DiSessa & Roschelle, 1995; Strike & Posner, 1992). Finally, researchers from Piaget (1985) to Karmiloff-Smith (1992) have tried to explain cognitive development in terms of so-called transition mechanisms (Sternberg, 1984). However, there is as yet no widely accepted description of a developmental transition mechanism. In general, any transformational account of cognitive change assumes the existence of powerful transformations that can traverse the space of possible conceptualizations without search.

In contrast, a *selectionist* account of cognitive change assumes that a new understanding of a domain or phenomenon begins by establishing an alternative cognitive starting point, an idea or concept that is established outside the learner's existing system of domain knowledge. Initially, such an alternative representation of the domain might be rudimentary, lack detail and have few concrete examples, justifications or arguments associated with it, and hence be completely dominated by the prior, well-established representation. However, over time, all available representations of a domain compete for attentional resources and a representation that is useful in dealing with certain types of situations or problems gradually gains strength and might eventually displace the previous representation. The existence of a compete/evaluate phase allows selectionist theories to postulate weaker and hence more plausible operations on prior knowledge than those required by a transformational account. Selectionist theories of cognitive

change also have support in biology and neuroscience (Calvin, 1996; Edelman, 1987; Plotkin, 1993; Sporns & Tononi, 1994).

This selectionist framework suggests a particular instructional strategy for supporting deep conceptual learning: fundamental ideas which contrast with the learner's current ideas need to be established on their own terms, so to speak, before they are brought into contact with the learner's prior ideas. In other words, a new idea should not be taught by directly confronting or transforming the learner's current idea, but by establishing an alternative knowledge structure or representation, a cognitive seed out of which a deeper understanding of the relevant domain can grow. After reviewing the evidence related to the learning of so-called ontological categories, Chi (1992) reached a similar conclusion: " ... instruction about a new ontological category must proceed by teaching this new ontological category of concepts independently of the old or existing conceptions." (p. 179) We claim that this conclusion holds not just for ontological categories, but for deep ideas generally.

This following pilot study illustrates the indicated strategy. The learning target in this study was the idea of evolution via natural selection. In preliminary work (Ohlsson & Bee, 1992, 1993) we verified that asking students to read a short exposition of the theory of evolution had minimal impact on their answers to explanation questions like "Why did the dinosaurs evolve to such a great size?" or "How did the tiger evolve its stripes?". As the learning paradox would lead us to expect, students' explanations for such adaptations are often radically non-Darwinian, even when produced *within minutes* of reading an exposition of Darwin's theory. Cross-breeding, large mutations, inheritance of acquired characteristics are among the explanatory principles spontaneously used. Even when students' explanations emphasize adaptation and survival, they rarely make use of the full explanatory machinery of natural selection. Obviously, this disappointing outcome is not due to memory loss but to lack of understanding. Prior ideas about biological change inevitably distort the message.

In response to this outcome, we taught the idea of variation and selection *in abstract form* before presenting information about biological evolution. We prompted reflection on such non-biological examples of selection as college acceptance and the US Olympic team, examples of replication such as copiers and art forgers, and such non-biological examples of change via variation and selection as best-sellers and technical innovation. The purpose was to prompt learners to create an abstract schema for change via variation and selection. Having established a cognitive beach head, as it were, for this new idea, we presented the learners with the same exposition of Darwin's theory that we used in previous studies, followed by the same explanation tasks. The approach worked: The students now understood the exposition at a deeper level, as evidenced by the higher quality of their explanations. The Darwinian exposition could be subsumed under the new schema of variation and selection, instead of under the learners' prior ideas about biological change, and hence escaped distortion.

To summarize, deep ideas are not acquired by a transformation of the learner's prior ideas, nor do they directly replace the latter. New fundamental ideas require alternative starting points, alternative representations of a domain. Once established, the alternative representation might gradually displace (rather than replace) the prior representation, depending on how useful it turns out to be. Hence, instruction for deep learning requires techniques for helping and prompting the learner to construct alternative representations of domains that might already be familiar from everyday experience. Advanced visualization technologies provide powerful tools for doing exactly that.

Advanced Visualization and Deep Learning

Deep learning requires alternative cognitive starting points. Advanced visualization technology enable multiple tactics for helping the learner create such alternative starting points. We specify five tactics that are embedded in the virtual worlds we will implement (see Section 2). There is no one-to-one mapping between tactics and worlds. Rather, each tactic is to be explored in the context of each virtual world, although the emphasis varies from world to world.

Tactic 1: Alternative experiences. The most obvious way to employ advanced visualization in the support of deep learning is to give the learner an alternative experience that relates to the relevant domain. Consider once again the problem of how to teach young children that the Earth is spherical. As we mentioned in the introduction, empirical research has demonstrated that it is difficult for children to understand the relation between themselves and a planetary body like the Earth, because they have nothing but their own experience to go by, and that experience is entirely consistent with the view of the Earth and sky as two separate layers, one above the other, where 'above' is understood in an absolute sense (Nussbaum, 1985; Vosniadou, 1994).

VR technology provides us with the possibility of giving children a qualitatively different experience: Walking on a planetary body where the curvature of that body is directly perceivable. We can design a virtual environment which recreates the perceptions that a person would have, were he or she to walk on a body with a very short diameter: the horizon looks curved, objects 'appear' from 'below' the horizon when one travels in their direction, a long trip takes

one back to where one started, etc. The virtual experience of actually 'visiting' a *visibly* spherical world generates a mental model that depicts the learner himself or herself as located on such a world. Once established, this mental model can grow and subsume other experiences and messages (e.g., seeing a 2D picture of the Earth as seen from space and being told that it is a picture of the Earth). This alternative model can eventually subsume the everyday experience of walking a seemingly flat Earth. This tactic is central to the Asteroid World that is the centerpiece of Project 2 (see Section 2).

However, the capability of providing qualitatively different experiences is utilized in the other virtual worlds as well. In the Garden (a virtual world that is already implemented; see Project 1), the learner can also experience a perspective that is only available in virtual reality: To descent below the surface of the soil and see the roots of plants growing downwards, as if from a ceiling. Unless someone invents transparent soil, this experience will be forever confined to virtual reality. Its effect on children's understanding of plant growth remains to be investigated.

Tactic 2: Switching representations. One consequence of our natural tendency to assimilate new information to our existing ideas is that each aspect or facet of reality tends to be 'seen' or conceptualized in only one way, within a single perspective. This cognitive tendency can be seen at work in so-called insight problems, objectively simple problems on which even intelligent people reliable get stuck until they suddenly see the solution in a flash of insight. The cognitive mechanism behind sudden insight is relatively well understood (Ohlsson, 1992; Sternberg & Davidson, 1995): Impasses on simple problems occur because the thinker assimilates or subsumes the problem under a prior conceptualization that does not, in fact, support the solution; impasses are broken when the representation is changed. The fact that even very intelligent adults can be stuck for minutes—even hours—on simple problems testifies to the difficulty of switching between mental representations. In argumentative contexts, the tendency to apply a single perspective might lead to so-called *my-side bias* (Perkins, 1995) instead of impasses, but the conclusion is the same: switching representations is hard. As we have argued in the introduction, deep learning may require precisely such shifts between alternative representations.

The obvious implication is that we should supply learners with the capability, not just of experiencing something different, but of juxtaposing and switching between representations, an implication that has been explored to some extent in the field of mathematics education (e.g., Dugdale, 1992). In 3D and VR 'worlds', we have unprecedented power to extend this tactic to other fields of learning than mathematics. We can provide the learner with interlinked, multiple representations of one and the same situation or experience and enable him or her to switch back and forth between them.

This approach is embedded in several ways in the Garden environment that is the centerpiece of Project 1 (see Section 2). The learner can vary his or her size along a continuous scale, and so view the Garden through either a bird's eye view, level with the sun and the clouds, or through a mouse's eye view, with the plants towering above his or her head, or from any level in between; the virtual Garden remains in view during the continuous shifts in size, so the relation between the different perspectives is directly experienced, as if the user were ascending or descending in a helicopter. However, perspective shifts are not limited to shifts that are, in principle, possible in the physical world. An 'impossible' possibility is to have designated 'vista points' strewn over the virtual landscape and give the learner a button by which he or she can instantly 'beam' himself or herself into any one of those points, thus giving him or her the capability of switching rapidly between, and so mentally juxtapose, alternative perceptions of the same (virtual) reality. Will such a capability affect Piagetian egocentrism in young children? We have to do the relevant studies to find out.

A different way to help the learner mix representations is to provide him or her with 'magical lenses' that can be held over a virtual object to reveal something about that object that is not ordinarily visible. This tactic is integral to both the Garden and the Temple 'worlds' (Projects 2 and 3; see Section 2). A magical filter might reveal (a) hidden structures, e. g., the cellular structure of a leaf, artifacts buried in the soil; (b) microscopic processes, e. g., absorption of water by a plant through its roots, the rotting of a wooden artifact; (c) an object's history or origin, e. g., what a plant looked like as a seedling or what a broken artifact looked like before it broke; (d) the object's name and definition; and so on. By passing the filter back and forth over the object, the learner can rapidly move between the normal (unfiltered) and the filtered views.

Advanced visualization technologies provide an infinite variety of techniques for helping learners move between alternative representations or perspectives. At this point, there is no theory in the learning sciences that can help us predict the reaction of learners to these possibilities. We cannot know without doing the relevant studies.

Tactic 3: Smart worlds. Because 3D and VR representations are computer-driven, the technology is at hand for augmenting them with artificial intelligence. In this project, we propose to explore two approaches to *smart worlds* that can respond intelligently to their 'visitors'. First, there is the question what role *intelligent avatars* can play

within virtual environments. An intelligent avatar is either a natural part of the represented environment (e.g., an animal in the virtual Garden; see Project 1), or a guide or coach (e. g., a scout on the Asteroid—see Project 2—or a friendly ghost in the Temple—see Project 3). An alternative approach is to make supposedly inanimate things into *magical objects* that can advice, help, or direct the learner. Such direction need not necessarily be verbal. For example, the plants in our virtual Garden 'tell' the user/learner that they are getting too much water by growing umbrellas. Finally, there is the possibility of *holistic adjustment*, in which the entire world adapts itself to the individual visitor. A simple example of this is to have a world adjust its own projection to the physical height of the user/learner so as to provide as natural a viewing angle as possible. We have began exploring such possibilities, but there is much work to be done in terms of investigating the power of smart worlds to support deep learning.

Tactic 4: Abstract worlds. The Garden, Asteroid and Temple worlds are virtual representations—and extensions—of physical reality. However, VR technology is not limited creating experiences of this sort. It also enables us to create abstract, totally artificial worlds that only have a conceptual or theoretical relation to direct experience. Examples of such artificial worlds are the Boolean networks that have been used to illustrate Darwinian principles; the so-called Game of Life is perhaps the most well known (Sigmund, 1993). The purpose of such worlds is to teach deep ideas in the abstract; once acquired, they can be transferred to one or more content domains. This instructional tactic is more appropriate with higher grade levels and more complex ideas.

One application of this tactic is to teach the concept of self-organization, i. e., the idea that systems with many parts and dense local interactions exhibit a tendency to spontaneously generate structure (Kauffman, 1995). This concept conflicts with the spontaneous and intuitive tendency to see organization and structure as produced by the action of a structuring agency, force or process, a tendency that Mitchell Resnick at MIT's Media Laboratory calls "the centralized mind set". With the help of advanced visualization technology, we can provide the learner with the experience of actually 'seeing' emergent properties arise from myriad local interactions (see Project 4).

Tactic 5: Bridging activities. The four tactics described so far provide us with considerable power to help learners construct alternative mental representations of particular facets of reality. Although crucial, this is not enough. Our over-all strategy dictates a second step: Eventually, the alternative representation must be brought into contact with the learner's prior knowledge of the domain and absorb or subsume it. Unless the learner eventually brings his or her experience in the Asteroid world into contact with the everday experience of walking a seemingly flat Earth, the learning objective is not reached. The point is not just to know what it would be like to walk on spherical planetary body, but to understand that the Earth is precisely such a body. At the end of the pedagogical day, the learner must come to interpret or understand his or her everday experience within the idea acquired in the course of visiting the Asteroid.

The last tactic in our educational strategy is therefore to help the learner interface their new ideas with their prior knowledge. We call activities that aim to do this *bridging activities*. We loosely distinguish between two types of bridging activities. *Embedded activities* aim to embed the link between virtual and non-virtual reality into the virtual environment itself. For example, exporting the size change feature from the Garden to the Asteroid allows the learner to directly observe that a curved horizon looks straight to the observer, if the observer is small enough. Here the link between the virtual experience of walking a visibly spherical world and walking the seemingly flat world are linked within the virtual environment itself via a continuous transformation. However, not all connections we want the learners to make are quite so neatly embeddable within the virtual representation.

Contextual activities embeds the 3D/VR experience within a larger instructional context where the relation between the virtual experience and everday experience is purposefully managed. To continue the same example, a visit to the Asteroid world will be followed by a 'debriefing' session, where the children are prompted to describe where they went with reference to a globe of the Asteroid. In this situation, the learner is in a position to project the virtual experience onto a representation accessible in normal space. The final step is to transfer that link onto the relation between everday experience and a globe representation of the Earth. Cognitive research on analogy (Clement, 1988; Gentner, Rattermann & Forbus, 1993; Holyoak & Thagard, 1995) provide a rich theoretical basis for the design of bridging activities.

Summary. We propose to investigate five tactics for supporting deep conceptual learning with advanced visualization technology: (a) By providing a (virtual) experience that is qualitatively different from everday experience. (b) By providing the learner with multiple representations and access paths to some situation or phenomenon, plus the ability to rapidly switch between them. Multiplicity and contrast are the key features here. (c) By endowing the visualizations with enough artificial intelligence to react to the learner in useful ways. (d) By providing abstract (but visualizable) instances of some deep idea, instances that have no direct counterpart in physical reality. This tactic is more appropriate with respect to young adults than children. (e) By helping learners construct conceptual bridges between the ideas they acquire in virtual space and their prior knowledge of the relevant domain.

Overview of Research Questions

The approach to the relation between deep learning and advanced visualization technology described above leads to five families of questions to be investigated in the context of the virtual 'worlds' described in Section 2.

First, the most fundamental question is how learners experience 3D and VR representations. This question is particularly important with respect to VR and with respect to young learners. When we design VR support for deep learning, we cannot take for granted that young learners experience the virtual environments in the same way as adults (particularly not the very same adults who built them and thus know what the 'right'—i. e., intended—experience is). Thus, one of our goals is to investigate how our virtual 'worlds' are understood by the learners who 'visit' them. We will draw upon the capability in the CAVE technology for detailed tracking of behavior as well as upon learner discourse to answer this question.

Second, how does advanced visualization interact with the cognitive processes involved in deep conceptual learning? Do 3D and VR worlds in fact help learners acquire deep ideas that can serve as starting points for a new understanding of a domain or a phenomenon? What features are crucial to make our instructional strategy work? For example, when, where and why is immersion essential and when not? How does the human cognitive system adapt to 3D and VR representations? To make the instructional strategy work, we need to develop bridging activities that enable the learner to make the connection between the alternative representation and his or her prior, intuitive knowledge of the relevant domain. What are the essential characteristics of bridging activities?

Third, what is the most effective use of artificial intelligence within advanced visualizations? Do intelligent avatars and magical objects increase the educational potential of 3D and VR environments, or do they interfere with the learner's exploration of these environments? What level of intelligence is enough? Should the intelligence be expressed in the actions of objects and agents within the virtual 'world' or in terms of some (suitably limited) discourse capability? Or should intelligence be employed primarily in the design of the virtual environment itself, so that the environment as a whole adapts itself to the learner?

Fourth, the creation of advanced visualizations requires novel modeling techniques and novel programming techniques. What are the technical problems involved in creating the visualizations outlined in Section 2? How realistic, or detailed, or fast, need a representation be to create the intended perceptual experience?

Fifth, how can advanced visualizations be interfaced with educational practice? One facet of this questions is how advanced visualizations might be combined with educational techniques that we already know are powerful. Recent educational research has emphasized the power of collaborative learning, particularly peer discourse (Brown & Palincsar, 1989). Virtual worlds and other advanced visualizations might have their most powerful educational impact as *something for learners to talk about*. How does one arrange scenarios that stimulate such talk? A second facet of this question is how to begin the task of injecting advanced visualization into educational practice.

2. PROPOSED WORK

In this section, we describe a sequence of advanced visualizations. The first, the NICE Garden environment, is already implemented and preliminary studies are already under way (for a description of NICE, see Tom Moher's "Results of prior NSF-sponsored work related to project" at the end of this project description). The subsequent environments are to be developed in the course of the project. For each environment, we develop its rationale and design, outline the activities that learners can undertake in those environments, and list the research objectives to be pursued with respect to that environment. The five research questions (see above) will be pursued with respect to each of the 'worlds' that we propose to develop, although the emphasis varies from world to world.

Project 1: The NICE Garden

Rationale. As described below, NICE was originally designed as an environment for young children to learn about the dependence of plants on sunlight and rainfall, the "spontaneous" growth of weeds, the ability to recycle dead vegetation, and similar simple biological concepts. While we believe that it has demonstrated some value in those respects, NICE has greater potential as a base for several extensions designed to address more directly issues of deep learning.

Design/Learner activities: We intend to extend the NICE Garden along several dimensions.

A current goal for NICE is to further refine the interface by developing techniques for more natural modes of interaction that improve the direct manipulation of the environment and don't interfere with the learning process. At present, simple navigational and manipulative tasks can be cumbersome, especially for young learners.

By adopting the story grammar-driven approach we demonstrated earlier in the Graphic StoryWriter (Steiner & Moher, 1992, 1994), we will allow learners to interact with avatars and props in the Garden in the context of a richer narrative structure than the current linear list of actions presently produced. We will incorporate speech synthesis and restricted speech recognition to support non-haptic interactions with the system.

We will add measurement tools to the Garden. At present, the growth of the flowers and vegetables can only be characterized qualitatively; we would like to provide a mechanism for quantifying growth in order to support deeper learning of the growth model than is presently possible.

We are investigating issues of self representation and non-verbal communication. The children greatly enjoy seeing other avatars in the virtual space. One of their favorite activities is to exchange flowers and thank each other by waving, moving their heads up and down, or bowing. They also like to visualize the presence of their body in the reflecting pools in the VR world. These directions provide potential for interesting studies in gesture communication and theatrical improvisation.

At present, collaboration in the Garden is rather free-form; all active participants share the same set of capabilities. However, we would also like to provide contexts in which users have an explicit co-dependence upon one another, through the assignment of distinct capability sets to different users.

Finally, we would like to make direct access to the growth model available to the learner. We would like learners to be able to set the parameters of the growth model to their choosing, for investigation by other students. Ideally, we would like to find a way to express these models directly within the virtual environment. For investigative or debugging purposes, this would also require user access to time acceleration, deceleration, and reversal.

Research objectives.

(a) Is the Garden an effective environment for self-directed learning about the growth of vegetation? Young children are unaware of the relationship between sunlight, moisture, and plant growth, but the Island on which the Garden sits is a highly engaging environment with an abundance of distractions. How can we facilitate children staying "on task" in such a visually rich environment?

(b) Unlike the projects to follow, the Garden is a representation of a commonly (though not universally, particularly in an urban area like Chicago) accessible and experienced environment. Is the match too close to support the selectionist model which we are advocating?

(c) How can we scale the Garden to accommodate more sophisticated users? The Garden seems an ideal environment for elaboration by extension to additional representations (e.g., zooming in to the cellular structure of leaves in the Garden.) Could the environment be augmented to support learning across, for example, the entire K-12 age spectrum, thereby creating the opportunity for long-term, decreasingly scaffolded learning?

Summary. The NICE garden is a currently active testbed for studying how children interact with an immersive virtual environment. This deals with both the pragmatic VR hardware and software issues in interacting with an immersive virtual world, as well as educational concepts embodied within that world.

Project 2: The Asteroid World

Rationale. Young children believe that the Earth is flat. More precisely, their mental model of the world separates “sky” and “earth” into two parallel layers, one “above” the other; the two directions “up” and “down” are absolute. Empirical studies have demonstrated that telling young children that the Earth is round does not cause their intuitive model to be replaced by a spherical conception of Earth. Instead, children assimilate the new information into their prior knowledge and conclude that the Earth is flat and *circular* (Nussbaum, 1985; Vosniadou and Brewer, 1994).

Children’s intuitive model of the Earth is natural, because it is consistent with—indeed, strongly supported by—everyday experience. Discourse has little impact, not only because words like “round” are ambiguous, but also because talk about the Earth is abstract and cannot compete with the vividness of traveling across a prairie, the feeling of looking upwards when looking at the sky, or of seeing the ocean with its straight horizon. Pictures have little impact, because they require a complex mapping between experience and the 2D plane: To understand a picture of a person on spherical body, the viewer has to project himself or herself *into* the picture, a cognitive achievement beyond very young children; the same is true for 3D representations (e. g., a globe). However, in VR the children can be *immersed* in the experience of walking on a spherical surface.

Design. The Asteroid world simulates the experience of walking on a planetary body—called the Asteroid—with a short diameter, a few hundred meters, but with normal Earth gravity (a necessary but harmless fiction). When donning the VR helmet (which in this world becomes a 'space helmet'), the learner has the experience of standing on a surface that slopes away in all directions; features of the landscape (rocks, etc.) are partially 'hidden' below the not-too-distant horizon; the latter is clearly curved. The Earth, the Moon and the Sun are visible in the sky above, as are some stars.

When the learner traverses the Asteroid environment, the simulation recreates the visual experience of walking on such a body: Objects gradually come into view above the horizon; objects in the sky (Sun, Earth, Moon, stars) 'move' in the opposite direction of travel; eventually, the sky objects 'set' below the horizon and become invisible because they are now 'behind' the Asteroid. If the learner walks far enough, he or she comes back to the starting point. As in the Garden environment, the learner can change his/her own size: As size increases, the horizon becomes noticeably more curved; if the learner shrinks to a very small size, the horizon starts looking more and more like the straight line we are used to seeing on Earth.

More than one learner can visit the asteroid at the same time. Each learner appears to the other as an avatar wearing a space suit. The avatar moves and turns in accordance with the learner's movements. If one learner 'walks' ahead of another who stays stationary, the 'walking' learner will be seen by the stationary one as gradually 'disappearing' below the asteroid's horizon.

Learner activities. Many different activities can motivate young children to explore the Asteroid world and become familiar with the visual experiences it provides. (a) The Survey. The asteroid is newly discovered and NASA needs a map of it. The 'surveying party' is equipped with map making tools to mark the different features they encounter as they traverse the Asteroid landscape (a rock, a giant toaster, or whatever it might be). (b) The Treasure Hunt. Space aliens have stored a treasure trove of alien artifacts on the Asteroid. Children 'land' on the Asteroid in 'search parties' of two or three, with the mission of finding the artifacts. (c) In a combination of these two activities, the map of the 'survey party' is used later by a 'search party' consisting of other children.

Research objectives. Three research objectives will be pursued in work with the Asteroid: A qualitative understanding of the young user's experience in the VR environment, the development of techniques for bridging to everyday experience, and solutions to the technical problems of creating the target experience.

(a) What do children experience during their 'visit' to the Asteroid World? How do they interpret the unfamiliar visual behavior of the surround? Is their interpretation the intended one, or do they conceptualize the experience in some unanticipated way? If so, is the pedagogical intent compromised? During 'debriefing' after their 'mission', the teacher ('mission leader') will stimulate children to talk about their experience on the Asteroid. Hearing another child describe the unfamiliar experiences might itself be considered part of the learning experience, but also provides us with insight into how they think about what they saw. We will also elicit drawings (in the context of the map making scenario). Past work in this area provides us with a base line against which to compare drawings collected from children who have visited the Asteroid.

(b) The second step in our instructional strategy is to help the children make the connection between the Asteroid experience and everday, Earth-bound experience. If our strategy works, it should be possible for children to assimilate everyday experience to the Asteroid experience; the former is like the latter, but on a very much larger body. To help the children build this bridge, the teacher will engage the children in 'post-mission' activities. For example, the teacher will ask the children to describe their visit with reference to a globe of the Asteroid ("show me where you went"), and then follow up with talk about traveling on Earth, with reference to a globe of the Earth.

The question is whether switching between Asteroid talk and Earth talk will enable the children to make the intended connection. To investigate this, groups of 2-4 children will be pretested in their normal classroom setting with the help of the interview questions and drawing tasks that have been described in the literature (Nussbaum, 1985; Vosniadou & Brewer, 1994). After visiting the Asteroid, the children will be encouraged to describe their experience. Finally, in their classroom setting, the children will be asked once again to answer similar questions and solve similar drawing tasks as before. Data analysis will emphasize a qualitative comparison between pre- and posttest answers.

(c) What representational techniques are needed to create the intended visual experience? How should sky objects 'move' in response to user movements to generate a feeling of 'rotation' as the user's head moves along a supposedly circular trajectory? How does one model the gradual appearance of an object over an horizon that is only a short distance away? How should the view of such a landscape transform itself under changes in observer size? The intended outcome here is a set of guidelines for how to create visual experiences of this sort.

Summary. The shape of the Earth is a test case for the educational potential of VR technology. The problem here is precisely immersion: We are always immersed in the experience of walking the Earth and due to the size of the planet, that experience is consistent with the intuitive, flat Earth model. Information to the contrary, communicated with discourse or pictures, tends to be assimilated into that model. Immersion provides the tool—or so we claim—to break out of this instance of the learning paradox and provide the children with a learning experience that establishes an alternative mental model within which a statement like "the Earth is round" can be understood in its intended meaning.

Project 3: Reconstructing the Temple of Bloom

Rationale. Human beings at all ages have difficulties with the use of evidence, particularly multiple sources of evidence, to support conclusions (Baron, 1988; D. Kuhn, 1991). We all too easily fall victims to a family of simplifications: the assumption that problems have *correct* solutions, the closely related assumption that there is a *single* solution or answer, the urge to *confirm* an initial hunch by seeking evidence consistent with it, and the equally strong urge to *reject* information that does not fit that hunch. The result is confirmation bias, or my-side bias (Perkins, 1995). These cognitive tendencies are particularly strong in reasoning about open-ended, ill-defined problems like those encountered in the social sciences and humanities (Carratero & Voss, 1994; Voss, Perkins & Segal, 1991). In this project, we focus on these cognitive tendencies in the context of reconstructing the past and the goal is to enlist the power of immersion to help middle-school and high-school learners construct an alternative conception of historical reconstruction as *informed imagination*, i.e., as a process of inventing the past, but not inventing it freely. The power of immersion is harnessed in demonstrating that there are multiple solutions to problems of reconstruction.

Design. The Temple environment represents some aspects of an archeological excavation. The basic scene is an outdoor site, a relatively flat expanse of ground; stereotypical landscape features (mountains, trees, church spires) might be visible in the distance but play no active role. Broken pieces of some ancient structure can be seen sticking out of the ground. We refer to the structure as a Temple, but its original function might be anything—indeed, determining the original function (fort? school? court?) is precisely the learner's task. The learner can 'excavate' the site by turning the VR wand into a 'dirt blower', thus uncovering the partially buried pieces. The ground also contains completely hidden pieces. They can be uncovered too, but there is no way of knowing in advance where they are. Thus, the learner has to search by selecting a location and 'digging' with the dirt blower. Different 'excavation teams' will be working with different sets of pieces.

Excavated pieces can be picked up, rotated, moved and connected by turning the VR wand into a 'power tool'. Once connected, the pieces stay connected. The construction is stable (even if its physical counterpart would not be). This capability allows the learner to reconstruct the Temple. With only some pieces available, most pieces broken, and no knowledge of what the structure looked like originally, the learner is facing a task of imagination and hypothesis formation as well as construction. Excavation and reconstruction can be carried out either in 3D or VR, providing an opportunity to investigate the differences between the two media.

To help with his or her reconstruction, the young archeologist has available an ancient text, written by an explorer who visited the Temple while it was still standing. (The text is written in a forgotten script, but it can be read by passing a magical lens over it; incidentally, the magical lenses provides a detailed record of access.) The text is fragmentary and incomplete, but describes what the ancient traveler saw in different parts of the Temple; partial drawings are included. The task is to reconstruct the Temple in such a way as to recreate those visual experiences.

Whether done in 3D or VR, *the learner can visit his or her reconstruction* in VR and so compare his or her own experience of walking through it with the ancient traveler's description. It turns out that there is more than one way to fit the pieces together. Hence, the 'excavation team' must decide how to allocate effort between finding more pieces, putting pieces together, evaluating the current reconstruction and taking pieces part and starting over. If the team is stuck, a friendly ghost appears and provides limited help by supplying additional evidence. Some excavated artifacts also have magical properties, e.g., the capability of showing where more pieces are buried, or providing other clues.

The ill-defined character of the task goes deeper than it first seems: There is more than one way to fit the pieces together so that the reconstruction fits with the traveler's diary. Thus, different excavation teams will not only be working with different pieces and different clues as to how they fit together, but they will come up with alternative reconstructions that have equally good fit to the traveler's diary.

Learner activities. An 'excavation team' of 2-3 children prepare by reading something about the culture that build the Temple. While excavating and reconstructing, they have to make joint decisions about how to fit the pieces together. After working for a while, the children exit the environment, and print pictures of their reconstruction. They argue over what could be changed or different. Their reconstruction remains and they can continue their work next week. In the meantime, they read more about the relevant era and culture in order to get more clues about what the Temple might have looked like. When they finished, they make a presentation to their classmates in front of the Infinity Wall, touring the reconstructed Temple and explaining how the pieces fit together.

Different teams present their reconstructions. If the reconstructions are different, the learners reenter VR and *tour each other's reconstructions* to verify that the different reconstructions do yield the target visual experiences, thus literally seeing the available evidence through another person's point of view. Debate about how to resolve this situation follows. In the final stage, the teacher ('expedition leader') moves the discussion into contact with actual historical reconstructions.

Research objectives.
(a) The main objective here is to investigate the impact of experiencing alternative solutions to a reconstructive problem on children's understanding of historical reconstructions. Can participation in a reconstructive activity and then having the (virtual) experience of an alternative solution to the very same problem increase awareness of good thinking dispositions (Perkins, 1995), such as seeking far and wide for evidence, looking for alternative interpretations, and avoiding confirmation bias? The key feature here is to be able to literally 'see the evidence' through another person's point of view.

(b) What bridging activities can help the learner transfer the insights gained in reconstructing the Temple into their understanding of real historical reconstructions? The crux here is to help the learner assimilate what they read about history to their experience in the Temple environment, rather than vice versa: 'real' historical reconstructions are like the task posed in the Temple environment, only more so.

(c) The traveler's ghost is an intelligent avatar—sometimes controlled by the learner's teacher, and sometimes operating on the basis of its own intelligence. What role should the ghost play in supporting reconstructive problem solving? The traditional task of a coach is to give feedback on the learner's progress, positive and negative. Here we plan to move beyond this paradigm and cast the ghost as an additional source of evidence, to be integrated with other sources (the shape of the pieces, the diary, etc.).

Summary. Efforts to improve young learner's thinking skills are typically carried out in the medium of language: Reasoning is verbal, it is assumed, and hence discourse seems to be the natural domain for training thinking skills. However, young people think as much in visual representations as in verbal ones. The Temple environment is a vehicle for studying and training thinking, particularly open-ended, evidence-based thinking, within a visual domain.

Project 4: The Growing Forests

Rationale. There is a general tendency in human cognition to attribute structure in the world to a structuring agency or process. Mitchell Resnick at MIT's Media Laboratory refers to this as *the centralized mindset*. However, research over the past decade has shown the prevalence of self-organization in nature (Kauffman, 1995). *Self-organization* can be defined as the tendency for large systems with many interacting parts to create or generate structural features in the absence of any structuring agency or process; the structure emerges out of the local interactions. The purpose of this world is to help young adults overcome the centralized mindset and replace it with the idea of self-organization. The vehicle is a stylized or schematic forest that can be seeded and grown to maturity in a short period of time. In its growth, it generates macro-structures, just like real forest: Meadows alternatives with trees; the density of different species varies over the landscape. The learner can change the starting point, and grow the forest again, seeing an alternative structure emerge out of the same processes.

Design. Unlike the Garden, the Forest does not aim for a naturalistic representation. The forest floor is flat and the plants are schematic structures, with just enough visuals to allow the learner to distinguish between different species. The plants grow very fast, from seedlings to mature trees in a few minutes. This allows the learner to grow the forest over and over again, watching the macro-structures appear, reappear or change across growth cycles.

Computationally, the forest floor is a *cellular automaton* (Sigmund, 1993). There is one plant to a cell. The cells value is 0 or 1; if 1, the plant grows one increment in the next cycle; if 0, it remains at its current size in the next cycle. The value of a cell for cycle n+1 is a function of the values of the neighboring cells in cycle n. Hence, growth is a function of local interactions. The interactions are specified by rules. There is a large number of possible rule sets. A particularly interesting rule set has been discovered by J. H. Conway; it forms the basis for the so-called

Game of Life. In our application, these rules say: If a plant is not growing, it will grow in the next cycle only if three of its neighbors are growing, otherwise not. If a plant is growing, it will continue to grow if two or three of its neighbors are growing, otherwise it will stop growing. This rule set has been shown to produce endlessly varying patterns and structures (Sigmund, 1993).

The forest is seeded by putting one seeding in each cell. The seedlings are from different plant species. There are categories of species: grasses, bushes and trees. The three categories are characterized by different growth rates (i.e., how large an increment in a growth cycle) and different maximal heights. The learner can seed the forest randomly, or by hand, choosing seedlings from boxes and planting them. The learner can control the growth rate, and thus slow down developments when something interesting is happening or speed them up otherwise. In addition, he or she can stop the Forest in mid-growth, and reverse time, thus watching the forest shrink back to its initial stage.

The growth of the Forest can be observed through an 'airplane view' in 3D; this gives an overview of the macro-structure of the Forest, the alternation of meadows and trees. The growth can also be observed in VR, where the learner are standing amidst the stylized trees as they grow from seedlings to trees all around in a matter of minutes.

Learning activities. The learner's main task is to specify the initial, 'seedling' state of the Forest, and to specify the rules of growth. Many aspects of the seedling state can be varied. The role of biodiversity can be studied by comparing the growth of a Forest with few species and one with many species in each category. The difference between random seeding and seeding large 'plots' with the same plant. More fundamentally, the learner can alter the initial rule set, thus controlling the local interactions. Once he or she is familiar with the interface, he or she can chose to give each species a separate set of growth rules; some plants thrive in the vicinity of other plants, others do not. By making each plant depend on other plants in different ways, the learner can study the relation between local interactions and final results. Finally, the learner can stop the Forest in mid-growth, 'clear' an area, reseed it and watch the consequences when the growth process is restarted.

Two types of activities will be explored in this environment. (a) Make it good. The learner's quest is to design a rule set that yields a pleasing Forest. What is pleasing is up to the individual learner, but whatever he or she decides it is, the task is to design a rule set that produces that effect. (b) Guess my botany. Two learners play against it each other. One learner designs a rule set; the other tries to figure out what it is by growing the Forest repeatedly, varying the initial state in informative ways. The final activity is, as always, to bridge between the experiences provided by the virtual world and other aspects of reality, and to prompt the learner to assimilate the latter to the former, rather than vice versa.

Research objective. The ultimate goal here is to use 3D/VR to give the learner an intuitive feel for the complex relation between an underlying causal mechanism of local interactions, and the 'projection' of that mechanism onto a plane of experience (Ohlsson, 1995b). The learning target is to understand that local, deterministic interactions can generate something random-looking like the alternation of plants in a forest. How powerful is this experience in fostering an understanding of self-organization? What are the bridging activities that will enable a learner to take this concept out of the 3D/VR environment and assimilate familiar processes (e.g., traffic jams) to that concept?

Summary. As science progresses, new concepts are created, and those concepts then become targets for learning and hence for instruction. The concept of self-organization, structure for free out of local interactions, is one of the more fundamental conceptual advances in the past decade. This late appearance of this concept is probably no accident; it goes against our natural tendency to infer a cause for macrostructures. Very little is known how this concept is understood by students. Advanced visualization technologies provide the possibility of immersing the learner in a representation in which he or she can watch emergence at work, so to speak.

Additional Project Opportunities

Petri Net Space. Recent research has called strongly into question the presumed superiority of graphical (as opposed to textual) representations of computer algorithms (Green, Petre, and Bellamy, 1991). However, we have shown that, appropriately configured, 2D Petri Net representations of algorithms can elicit subject performance (comprehension) comparable to that of textual representations (Moher, *et. al.*, 1993). 3D and VR provide further opportunities for spatial configuration which should be explored. In addition we have developed 2D environments in which virtual objects (props and characters) are directly mapped, positionally, to formal net elements, with simulation of the net rendered as the movement of animated characters within the environment. This could provide a simple programming mechanism for childrens' construction of virtual worlds.

The Visible House. Most people have very weak mental models of the infrastructure systems embedded within houses. By extending the notion of movable filters, see-through tools, and magic lenses (Stone, Fishkin, and Bier,

1994; Bier, Stone, Fishkin, Buxton, and Baudel, 1994) to volumes (with selectable user "auras" substituting for the 2D filters and tools typically assigned to the non-dominant hand), users would have the opportunity to explore discrete subsystems. More interestingly, this could be turned into a diagnostic task requiring collaboration among remote participants.

3. ADVANCED VISUALIZATION IN EDUCATIONAL CONTEXT

Teaching and Studying Teachers

Teaching, especially for novices, is complex, confusing, and isolating. "In a classroom, there is no one to ask about how to unleash imagination, curb undesirable behavior, treat a crowd as a collection of interesting individuals, or make learning its own reward. Good ideas from [a university] dim in importance, and impulse and reaction to classroom events take their place" (Garner & Gillingham, 1996, p. 90). In order to help student and novice teachers become expert teachers, teacher educators have attempted to incorporate the right mix of knowledge including subject matter, general teaching strategies, and pedagogical content knowledge, which is knowledge about the teachability of a subject matter. Each of these types of knowledge is complex, mastery takes time and is never certain. Observing an expert teacher work his or her magic in the complex environment that is a classroom, like complexity itself, is difficult to describe; "everybody talks about it, but nobody knows what it really is" (Dan Stein quoted in Johnson, 1997, May 6). In spite of teaching complexity, it is goal of teacher educators to learn how to teach teachers to teach well in classrooms.

Educators in science, mathematics, and other subject matters have rejected a model of teaching in which the teacher (textbook or computer) only tells the content to the student (transmission model) in favor of constructivist models of teaching in which students' thinking and understanding are the focus (c.f., standards of professional teacher education organizations: NCTM, AAAS, NSTA). The teacher's role in constructivist classrooms is not to lecture, explain, or transfer knowledge, but to create experiences for students that will foster their mental constructions through his or her own explanation, evaluation, communication, and application of discipline specific models. Within this constructivist model, students need to engage in the environment using the cultural tools of that environment in order to make meanings. Practical action within this environment, which includes human resources (parents, peers, and teachers), leads to learning and understanding (Nueman & Roskos, 1977).

As a model of teaching, constructivism can make predictions about teaching methods and environments. One can predict, for instance, that learners in environments following constructivist principles will have more or deeper understanding or that a teacher will know more about a learner due to constant teacher-learner negotiation within a constructivist environment. But how does a teacher become proficient in this student-centered pedagogy that requires one to negotiate with students, elicit thinking about their knowledge representations, arrange students together, act as a mediator, guide, provocateur, friend, and colearner (Tobin, Tippins, & Gallard, 1994)?

Typically in teacher education, students are brought into close proximity to knowledge in the hope that some interaction will occur, but constructivist principles would dictate that a teacher take into account a student's prior knowledge, provide appropriate social experiences, and help students to reflect on their experiences for understanding. What is a good learning environment for students is a good learning environment for teachers. That is, the environment should allow the teacher to make explicit his/her knowledge about teaching and learning and allow for explicit representation of this knowledge. In addition, the environment should allow experiences that are relevant to concepts or processes being taught. Finally, teachers must be allowed to reflect on their new experiences and developing understanding of teaching. Within the model of teacher as learner, we think the proper study for teachers is their own teaching within the same environment in which we would have students learn.

Constructing Teacher Knowledge in Virtual Social Environments

Teacher as Wizard. Within the NICE environment, teachers can make their knowledge of general teaching strategies and particular content-based teaching strategies known by controlling an avatar that interacts with students working in the environment. Like the Wizard of Oz, the teacher is a wizard working safely behind the curtain. This distance from the "real" classroom and from the students offers several advantages for developing teachers. First, the distance offers the teacher a social safety net. Novice teachers may show visible fear that students can see or sense. The avatar wizard cannot show such emotion. Second, the wizard can have a local support system that is not possible in a real classroom including notes, references, tools, and other humans as expert coach or peer. Because much of the confusion of a real classroom is reduced in the virtual classroom, the wizard has more time between actions to think, find information, consult with others, and reflect on previous actions.

The Wizard's avatar is an instantiation of knowledge about teaching. In most real and simulated teaching environments, a student teacher's knowledge is mostly hidden except for what can be inferred through speech and actions. In the virtual classroom, however, the Wizard makes his or her knowledge explicit through the act of controlling the avatar. All of the controlling actions are intercepted and interpreted via a computer, which stores the states of the classroom and all of its actors. Thus we can know important information about general teaching strategies (e.g., when to introduce a measuring instrument) and content-specific strategies (e.g., how to introduce a measuring instrument). In addition, we can know information about the resources that the wizard has used and the side conversations with any peer or expert guides. Thus, we as the teacher of the teacher can understand much more about what a novice teacher knows than in real settings or other simulated settings (e.g., microteaching).

Playing back the virtual scenario stimulates reflection on practice. Learning in a constructivist environment requires a learner to think back on previous activities and on current understandings. The virtual classroom environment allows the teacher to replay previous interactions in a world. During these replays, teachers can explain or discuss their actions with peers, expert teachers, or interested researchers. When peers talk to one another about teaching, they learn a new language in which to discuss their pedagogy that allows them to discuss pedagogy more easily and more precisely in the future. When novice teachers discuss a replay with an expert teacher, they get to "see" what alternative actions might have been. actions can be added to their teaching repertoire to be tried out in the future. We as researchers can eves drop on peer and novice-expert discussions as well as prepare special settings for stimulating discussions to help answer particular research questions.

4. SIGNIFICANCE

The significance of the proposed work resides in (a) the focus on deep learning, (b) our selectionist framework and the strategy for supporting learning that we derive from that framework, (c) our plan to employ an existing advanced technology capability in the service of that strategy, (d) our proposals for how to augment that capability, and (e) the goal of developing models for injecting the technology into educational and other socially important contexts.

(a) Recent work in the learning sciences has been successful in clarifying the cognitive processes involved in reading and practice, but as we have argued elsewhere (Ohlsson, 1990, 1995), theories of text comprehension and skill acquisition tend to confirm rather than revolutionize common sense conceptions of learning. Hence, the implications of those theories have limited impact. The proposed work is significant in its focus on deep conceptual learning, i. e., the acquisition of ideas which are more fundamental than the learner's prior ideas. A theory of deep learning would significantly extend the learning sciences and contribute to the formation of a recognized subfield devoted to the study of deep learning.

(b) In the past, deep learning has typically been addressed within the assumption that new knowledge is produced by the application of operations (learning mechanisms, transition mechanisms) to prior knowledge. However, it is not obvious that such a *transformational* account of cognitive change will ultimately be successful, and the learning sciences need to explore alternative conceptions. The proposed work is significant in that it attempts to formulate a *selectionist* framework for understanding deep learning. New conceptualizations are seen as growing out of alternative cognitive starting points and gradually superseding—as opposed to transforming or replacing—prior knowledge. This approach to cognitive change ignores the stale dichotomies (symbolic vs. connectionist, cognitive vs. situational, positivism vs. constructivism, etc.) that characterize many current debates in the learning sciences and it provides an alternative starting point—thus practicing what it preaches. The proposed research will enable us to empirically evaluate the selectionist approach to deep learning.

Until recently, educational research has been dominated by a communication metaphor: instruction is the communication of knowledge by those who have it to those who do not. This metaphor provides no conceptual tool for dealing with the fact that the learner's existing knowledge is his or her main tool for understanding any communication. New information tends to be assimilated to—or subsumed under—existing concepts and ideas. If what is communicated is an idea more fundamental than the learner's current ideas, the result is often distortion. The proposed work is significant in that it attacks this learning paradox head on. We propose to teach fundamental ideas by providing the learner with alternative cognitive starting points for understanding a domain or a phenomenon. One of the intellectual products of the proposed work is a conceptual and empirical evaluation of this strategy for supporting deep learning.

(c) The proposed work aims to develop the implications of our theoretical framework within the context of an existing advanced technology capability. Novel symbol formation technologies tend to change and alter how human beings go about cognitive and intellectual tasks—indeed, they tend to change those tasks themselves. This statement applies to learning as well. As advanced visualization technologies gradually become more widely available, they will begin to change the workplace and the classroom (as they have already changed the video game arcade). The proposed

work is significant in that it will increase our understanding of the interaction between these technologies and human cognition. One goal of this work is to clarify how best to employ—and, perhaps, when not to employ—advanced visualization technologies. Although we focus on educational contexts in the proposed work, this project is part of a broader effort at the Electronic Visualization Laboratory to understand the role of advanced visualization technologies in human affairs generally.

(d) Tools are typically invented for a particular purpose; the computer, in contrast, is such a universal tool that it requires research to figure out how we want to use it. Advanced visualization technologies like 3D and VR can develop in many different directions, and it is not *a priori* obvious which directions are most useful or interesting. We propose to explore different approaches to augment advanced visualization with artificial intelligence. Intelligent avatars, magical lenses and holistic adaptation to the learner are three such approaches. We will explore each of these approaches within different virtual 'worlds'. At the end of the project period, we will be in a position to make a research-based statement about the possibilities and problems encountered in each type of extension.

(e) A novel symbol formation technology, if it is going to have societal impact, must be interfaced with current social practices and it matters how, when, where and to whom it is introduced. Unless alternative models are put forward, shoot'em-up video games will become the primary social use of advanced visualization technologies and the potential of these technologies to become powerful tools for the enhancement of human scientific, practical and artistic achievement will remain unrealized (Norman, 1995; Perkins, 1993). The proposed work is significant in its attempt to develop explicit models for how to inject advanced visualization technologies into educational contexts. We see this as one instance of the more general problem of how to interface advanced visualization technology with socially important practices and institutions.

RESULTS OF PRIOR NSF-SPONSORED WORK RELATED TO PROJECT

Thomas Moher

The NICE project—a virtual Garden implemented in a CAVE—was begun in the summer of 1995 to study how virtual reality could be used to stimulate 6-10 year old children to think about plant biology. The project, benefiting from the equipment made available through an NSF CISE grant, has acted as a testbed both for implementing educational concepts within a virtual reality setting, and the virtual reality technology (user interfaces, computer graphics, networking, persistence) necessary for realizing those concepts (Roussos et. al., 1996, 1997). The various pilot studies carried out within the Garden have dealt with such pragmatic issues as how young children react and adapt to an immersive virtual world, how they interact with other children within that world, and whether they can effectively use the relevant interface technology.

NICE focuses on issues of Narrative, Exploratory, Immersion, Constructivism, and Collaboration on a virtual island. The children's main activity on this island is the tending of a virtual garden. A garden was chosen because it provides a familiar setting that involves complex real-world systems as well as constructive activities. Within the virtual garden, the complex interrelationships of a real garden can be simplified to make them more obvious. The virtual world gives children abilities they do not have in the real world, for example, the ability to shrink down to the size of a mouse and walk underneath the soil to see the roots of flowers and vegetables. The use of a garden also provides the opportunity to compare children working in the virtual garden and children working in a real garden.

NICE is a dynamic, persistent virtual environment which is constantly growing, even if no one is present. Like a real ecosystem, it changes even when unobserved. Since the 'world' is constantly running, children can enter the world at any time and interact with whomever and whatever they find there.

In the garden the kids can pick a seed from one of the crates and drop it on the ground, the corresponding plant, flower or tree begins to grow. The children must make sure that their plants are not too close together, and that they get enough water and sunlight. They can water the vegetables by pulling a rain cloud over them and provide sunlight by pulling over the smiling sun. When a plant is adequately watered, it pops up an umbrella and the children pull the cloud away; when the sunlight is too bright, the plant wears sunglasses; when it feels crowded it starts moving restlessly. Groups of children can work together to keep their garden clean and healthy. They exchange seeds and flowers, they clear out the weeds by recycling them in the compost heap, and they gather the successfully harvested vegetables in a barrel. Sofia, the friendly owl, provides constant assistance, and the birds might help with the planting.

NICE supports the constructionist view that learners assimilate knowledge by engaging in self-directed learning activities which are accomplished through constructive tasks. Exploration and the process of constructing objects are viewed as integral parts of these learning activities. In NICE, constructive play is made possible with virtual building blocks that contain characteristics physical toys or learning tools do not: the kids can pick up impossibly large objects, hand them to other remotely located children, combine them to build new objects, or instantly observe their changing attributes over time. They can determine the environment characteristics, change their own body size, disappear, fly, or leap high in the air.

The constructive artifact (Papert, 1980) in NICE is the garden itself - which is persistent. Even when there are no children in the virtual world, it continues to change through time; the plants grow, the weeds take over neglected gardens, and the flowers wilt when not watered. Another artifact is the narrative - the stories formed and created by the kids that participate. The narrative revolves around the tending of the garden and the reactions or decisions taken while interacting with other users.

This story sequence goes through a simple parser, which replaces some of the words with their iconic representations and publishes it on a WWW page. This gives the story a picturebook look which the child can print to take home. Most of the time these stories do not accomplish narrative closure, rather they come across as a series of interactions between the characters and the world. Nevertheless, the children enjoy this process, especially when they get to take home the written and illustrated version of the narrative in either printed or electronic form, or an electronic version of the scene, generated as a virtual model. The two-dimensional version of NICE also allows the children to interact with the three-dimensional VR space and create their stories through the use of Java applets on the Internet.

Equally important to the construction of one's knowledge is the experience gained by participation in group activity. Collaboration is emphasized in NICE through the combination of collaborative learning across both virtual, as well as physical communities. The network component of NICE allows multiple networked participants at different locations to interact with each other and share the same virtual space. The representation of each tracked child in the virtual space is established through the use of an avatar with a separate head, body, and hand. As each person's head and hand are tracked, this allows the environment to transmit gestures between the participants such as the nodding of

the user's head, or the waving of the user's hand to the other participants. Visually, the wand is mapped to the arm of the child's avatar. As the child waves her hand in the real world, her avatar waves its hand in the virtual world. As these avatars have sufficiently detailed representations, the children can communicate notions of relative position to one another with phrases such as "it is behind you" or "turn to your left." The use of audio (with wireless microphones) between the various sites enhances the communication process.

Teachers or parents can participate, either as members of the groups, or disguised as characters or animals. This allows teachers to advise the children in person or to direct parts of the activity from "behind the scenes". They can also predetermine the pace at which the world evolves; they may choose to see the plants grow very quickly, or, in the case of a school project, extend their growth over the period of a semester. The activities in the NICE environment can be recorded as a 3D movie and then played back in VR allowing a teacher and students to relive and talk about their actions and decisions in the virtual world.

Collaboration also involves the social interaction among children located in the same physical space. Theories that emphasize the importance of social interaction in cognitive growth [Vygotsky, 1978] suggest that successful collaborative learning involves more than the final creation of a learning product. Learning that is contextualized in a social setting may involve verbal interaction, collective decision making, conflict resolutions, peer teaching, and other group learning situations characteristic of a classroom setting. With the use of VR technology that supports multiple users in the same physical space, as well as appropriate interaction techniques, a number of kids can participate in the learning activity at the same time, without having to take turns or wear heavy and intrusive hardware devices.

Some work has already been done in NICE to integrate a web-based component into the virtual environment, allowing children on the Internet to see the current state of the garden and even help tend the garden from a web browser. The children can increase their contact with the virtual world beyond the immersive experience itself. Further research involves expanding access to the virtual world from the web, and how the best features of immersive virtual reality and the web can help support each other.

MANAGEMENT PLAN

Tom DeFanti, PI, will serve as the chair of the project's Research Review Committee, consisting of the PI, all Co-PIs, and Senior Personnel. This committee will meet monthly for the purpose of reviewing the progress of projects and determining resource needs and priorities for the next month.

Stellan Ohlsson, Co-PI, will serve as the senior learning specialist on the grant, with primary responsibility for the design and implementation of observational and experimental work relating to the project.

Andy Johnson, Co-PI, will serve as the senior technology specialist on the grant, with primary responsibility for the design and implementation of the VR 'worlds' developed under the grant. Maria Roussos, Senior Personnel, will provide direct support to Dr. Johnson, and will in turn directly supervise students engaged in design and implementation efforts.

Mark Gillingham, Senior Personnel, will serve as the senior education specialist on the grant, with primary responsibility for the design of effective mechanisms for deploying advanced visualization technologies in the classroom; Dr. Gillingham will also serve as primary liaison with our partner schools.

Tom Moher, Co-PI, will serve as the senior learning technologies specialist on the grant, with the specific responsibility for facilitating cross-disciplinary interaction among team members and dissemination of results.

The seven graduate students will be selected and tasked by the Research Review Committee as a whole, in response to the skill sets required at varying points in the project. We have specifically chosen not to allocate graduate students to specific investigators at the outset. (In the long-standing interdisciplinary tradition of the Electronic Visualization Laboratory, we hope to blur the distinctions between departments for the graduate students.) The graduate student team will meet on a bi-weekly basis along with one or more of the Research Review Committee members, depending on the needs of the project.

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Werner, H., & Kaplan, B. (1963). *Symbol formation*. New York: Wiley.

BIOGRAPHICAL SKETCH

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D. A list of the names of graduate students with whom this individual has had an association as thesis advisor and postdoctoral scholar sponsored by this individual over the past five years, with a summary of the total numbers of graduate students advised and postdoctoral scholars sponsored.
E. The names of this individual's own graduate and postdoctoral advisors.

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Thomas A. DeFanti, Ph.D., is director of the Electronic Visualization Laboratory (EVL), a professor in the department of Electrical Engineering and Computer Science, and director of the Software Technologies Research Center (STRC) at the University of Illinois at Chicago (UIC). He is also the associate director for virtual environments at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign.

EVL is a joint effort of UIC's College of Engineering and School of Art and Design, and represents the oldest formal collaboration between engineering and art in the country offering graduate degrees in visualization. Current research interests include: virtual environments, digital libraries, scientific visualization, new methodologies for informal science and engineering education, paradigms for information display, distributed computing, algorithm optimization for scalable computing, sonification, human/computer interfaces, and abstract math visualization.

Over the past several years, EVL faculty and students, with expert knowledge of advanced computing, visualization and networking, have been collaborating with other researchers who have expert knowledge of particular application areas but limited working knowledge of computing. Together, they are producing powerful new tools and techniques that would not have been possible had they acted individually. Under the auspices of STRC, EVL has strong working collaborations with other UIC departments, as well as NCSA and Argonne National Laboratory.

DeFanti is an internationally recognized expert in computer graphics. In the 24 years he has been at UIC, DeFanti has amassed a number of credits, including: use of EVL hardware and software for the computer animation produced for the first "Star Wars" movie; early involvement in video game technology long before video games became popular; contributor and co-editor of the 1987 National Science Foundation-sponsored report "Visualization in Scientific Computing;" recipient of the 1988 ACM Outstanding Contribution Award; an appointment in 1989 to the Illinois Governor's Science Advisory Board; University Scholar for 1989-1992; appointed an ACM Fellow in 1994; appointed one of several USA technical advisors to the G7 GIBN activity in 1995; appointed to the Internet 2 Advisory Committee in 1997; and, recognition along with EVL co-director Daniel J. Sandin for conceiving the CAVE virtual reality theater in 1991.

He has also been active in the ACM SIGGRAPH organization and in the ACM/IEEE Supercomputing conference. Current and past activities include: secretary of ACM SIGGRAPH (1977-1981); co-chair of the SIGGRAPH 79 conference; chair of ACM SIGGRAPH (1981-1985); past chair of ACM SIGGRAPH (1985-1989); editor of the "SIGGRAPH Video Review" video publication, which he founded in 1979; and, member of the SIGGRAPH 92 and SIGGRAPH 94 conference committees. He was information architect on the Supercomputing 95 conference committee, responsible for the I-WAY and GII Testbed activities, and is a member of the Supercomputing 97 Program Committee.

PUBLICATIONS RELATED TO PROPOSED PROJECT

T. DeFanti, I. Foster, M. Papka, R. Stevens, and T. Kuhfuss, "Overview of the I-WAY: Wide Area Visual Supercomputing," International Journal of Supercomputer Applications and High Performance Computing, 1996, Vol. 10, No. 2/3, Summer/Fall 1996.

J. Leigh, A. Johnson, T. DeFanti, "CALVIN: an Immersimedia Design Environment Utilizing Heterogeneous Perspectives," Proceedings of IEEE International Conference on Multimedia Computing and Systems '96, Hiroshima, Japan, June 17 - 21, 1996.

J. Leigh, A.E. Johnson, C.A. Vasilakis, T.A. DeFanti, "Multi-Perspective Collaborative Design in Persistent Networked Virtual Environments," Proceedings of the IEEE Virtual Reality Annual International Symposium (VRAIS 96), Santa Clara, CA, March 1996.

T.A. DeFanti, D.J. Sandin, G. Lindahl, M.D. Brown, "High-resolution and High-bandwidth Immersive Interactivity," Very High Resolution and Quality Imaging Conference, SPIE Proceedings, Vol. 2663, February 1996, pp. 28.

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OTHER SIGNIFICANT PUBLICATIONS

T.A. DeFanti, D.J. Sandin and C. Cruz-Neira, "A 'Room' with a 'View'," IEEE Spectrum, October 1993, pp. 30-33.

C. Cruz-Neira, J. Leigh, C. Barnes, S.M. Cohen, S. Das, R. Engelmann, R. Hudson, M. Papka, T. Roy, L. Siegel, C. Vasilakis, T.A. DeFanti and D.J. Sandin, "Scientists in Wonderland: A Report on Visualization Applications in the CAVE Virtual Reality Environment," IEEE 1993 Symposium on Research Frontiers in Virtual Reality, October 1993, pp. 59-66.

C. Cruz-Neira, D.J. Sandin, T.A. DeFanti, "Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE," Computer Graphics (Proceedings of SIGGRAPH 93), ACM SIGGRAPH, August 1993, pp. 135-142.

C. Cruz-Neira, D.J. Sandin, T.A. DeFanti, R. Kenyon and J.C. Hart, "The CAVE: Audio Visual Experience Automatic Virtual Environment," Communications of the ACM, Vol. 35, No. 6, June 1992, pp. 65-72.

B.H. McCormick, T.A. DeFanti, and M.D. Brown (eds.), Visualization in Scientific Computing, Computer Graphics, Vol. 21, No. 6, ACM SIGGRAPH, November 1987.

COLLABORATORS DURING PAST 48 MONTHS

Larry Smarr, NCSA; Charlie Catlett, NCSA; Rick Stevens, Argonne National Laboratory (ANL); Tim Kuhfuss, ANL; Ian Foster, ANL, Dan Sandin, UIC; Maxine Brown, UIC; Robert Kenyon, UIC; Tom Moher, UIC; Robert Grossman, UIC; David Naylor, UIC; Lewis Sadler, UIC; Ahmed Kassem, UIC; Pat Banerjee, UIC; Jim Bower, Caltech.

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David Adamczyk, Cheong Ang, Craig Barnes, Steve Cohen, Carolina Cruz-Neira, Marek Czernuszenko, Sumit Das, Roger M. Engelmann, Morteza Ghazisaedy, Javier Girado, Jon Goldman, Robert Grzeszczuk, John Hart, Milana Huang, Randy Hudson, Andrew Johnson, Verne Jones, Ivan Judson, Jason Leigh, Kai Martin, Joanna Mason, Paul Neumann, Dave Pape, Mike Papka, Chris Pratico, Ramesh Ramakrishnan, Maria Roussos, Trina Roy, Lewis Siegel, Rob Stevenson, Matt Szymanski, Marcus Thiébaux, Chris Vasilakis, Alan Verlo, Donna Wolf

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Dissertation advisor: Lee J. White, Case Western Reserve

BIOGRAPHICAL SKETCH

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Andrew E. Johnson, PhD. is a post-doctoral researcher at the Electronic Visualization Laboratory at the University of Illinois at Chicago. In the Fall of 1997 he will join the faculty of the Electrical Engineering and Computer Science Department as an assistant professor. He holds a B.S.E in Computer Engineering from the University of Michigan at Ann Arbor, and an M.S. and PhD. in Computer Science from Wayne State University in Detroit.

His research focuses on collaboration in immersive virtual environments. In the CALVIN project, working with DARPA, he helped design, implement, and study a testbed for transcontinental collaborative design in virtual environments which was used in a collaborative design session at Supercomputing '95 between San Diego and DARPA in Arlington Va. In the NICE project he is currently studying how collaborative virtual environments can enhance childhood education, and how to make virtual environments more accessible to children. The NICE has been demonstrated in transcontinental collaborations at SIGGRAPH 96, Supercomputing '96, and Thinkquest '96.

PUBLICATIONS RELATED TO PROPOSED PROJECT

"Supporting Transcontinental Collaborative Work in Persistent Virtual Environments." with Leigh, J., In IEEE Computer Graphics and Applications, Vol 16.4, July 1996, Pp 47-51.

"Constructing Collaborative Stories Within Virtual Learning Landscapes." with Roussos, M., Leigh, J., Vasilakis, C., Moher, T., In proceedings of the European Conference on Artificial Intelligence in Education '96. Lisbon, Portugal, Sept 30 - Oct 2, 1996, Pp 129-135.

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"Adaptive Clustering of Hypermedia Documents." with Fotouhi, F., In Information Systems , Vol 21.6, November 1996, Pp 459-473.

OTHER SIGNIFICANT PUBLICATIONS

"CALVIN: an Immersimedia Design Environment Utilizing Heterogeneous Perspectives." with Leigh, J., In proceedings of IEEE International Conference on Multimedia Computing and Systems '96. Hiroshima, Japan, June 17 - 21, 1996, Pp 20-23.

"Data Retrieval through Virtual Experimentation." with Fotouhi, F., In Computer Graphics: Developments in Virtual Environments (proceedings of Computer Graphics International '95 , Leeds, England, June 25-30), Eds Earnshaw & Vince, Academic Press, 1995, Pp 393-409.

"The SANDBOX: a virtual reality interface to scientific databases." with Fotouhi, F., In proceedings of the Seventh International Working Conference on Scientific and Statistical Database Management, Charlottesville, Virginia, Sept 28-30, 1994, Pp 12-21.

"The NICE Project: Narrative, Immersive, Constructionist / Collaborative Environments for Learning in Virtual Reality." with Roussos, M., Leigh, J., Barnes, C., Vasilakis, C., Moher, T., To appear in proceedings of the ED-MEDIA '97. Calgary, Canada, June 14 - 19, 1997.

"Adaptive indexing in very large databases." with Fotouhi, F., In Journal of Database Management, Vol 6.1, 1995, Pp 4-12.

COLLABORATORS DURING PAST 48 MONTHS

Joseph Hardin, NCSA; Mike Kelley, (DARPA); Satyendra Rana, Wayne State University (WSU); Narendra Goel, (WSU); Richard Weinand (WSU), Tom DeFanti, Tom Moher, Stellan Ohlsson, Maria Roussos

GRADUATE STUDENTS

None.

GRADUATE AND POSTDOCTORAL ADVISORS

Dissertation Advisor: Farshad Fotouhi, Wayne State University
Postdoctoral Advisor: Thomas DeFanti, University of Illinois at Chicago

BIOGRAPHICAL SKETCH

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Tom Moher's current research focuses on three areas: interactive learning environments, cognition and programming, and formal models of human-computer interaction. In the area of learning environments, his Graphic StoryWriter system is a (2-D) virtual learning environment for pre-literate children, providing a scaffolding mechanism for the construction of narrative texts. Another educational system, SMILE, permits early interventionists to use simple Petri nets to describe learning activities for cognitively impaired young children. More recently, his work has focused on learning in VR environments, particularly the NICE project (described in this proposal).

In the area of cognition and programming, Moher has focused on programming language constructions and their impact on comprehensibility--particularly Petri nets--for programmers and non-programmers. More recently, he has worked in the area of trying to unify modeling formalisms for representing and designing interactive systems.

In addition to his University responsibilities, Moher is an elected member of the Board of Education of the District 97, Oak Park, Illinois Public School system. In that capacity, he has been active in helping to lead a major technology initiative, and has provided direct training and software development within the District. He has also served on a variety of committees devoted to topics surrounding educational reform, and their implementation within the District.

The ICE laboratory has received major funding from the National Science Foundation, U.S. Department of Education, Office of Naval Research, Argonne National Laboratory, Illinois State Board of Education, the GTECH Corporation, and the University of Illinois, with annual funding at a rate of about $350,000 over the past five years. Moher is Co-PI on the NSF CISE Infrastructure Grant currently in place at UIC.

CURRENT POSITION

Associate Professor, Department of Electrical Engineering and Computer Science, University of Illinois at Chicago (UIC). Joined UIC in 1980.

EDUCATION

Ph.D., Computer Science, University of Minnesota, 1983.
S.B., Computer Science, University of Michigan, 1972.

PUBLICATIONS RELATED TO PROPOSED PROJECT

"The NICE Project: Narrative, Immersive, Constructionist / Collaborative Environments for Learning in Virtual Reality" (with M. Roussos, A. Johnson, J. Leigh, C. Barnes, and C. Vasilakis), to appear in *Proceedings of the ED-MEDIA '97*. Calgary, Canada, June 14 - 19, 1997 (best paper award).

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"Scaffolding Story Construction with Interactive Multimedia" (with K. Steiner), *Proceedings ACM Conference on Human Factors in Computing Systems (CHI'92)*, Monterey, CA, May 1992.

"Revising Mental Models to Accommodate Expectation Failure in Human-Computer Dialogues" (with V. Dirda), *Design, Specification, and Verification of Interactive Systems '95,* P. Palanque and R. Bastide (Eds), Toulouse, France, June 1995, pp. 76-92, Springer-Verlag.

OTHER SIGNIFICANT PUBLICATIONS

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"A Comparison of Verbal Interaction Between Young Users in Literal and Virtual Shared Learning Environments" (with K. Steiner), *Proceedings ACM Conference on Human Factors in Computing Systems (CHI '94)*, Vol. 2, Boston, MA, May 1994, pp. 97-98 (short paper).

"Comparing the Comprehensibility of Textual and Graphical Programs: The Case of Petri Nets" (with D. Mak, B. Blumenthal, and L. Leventhal), in C. Cook, J. Scholtz, and J. Spohrer, Eds., *Empirical Studies of Programmers: Fifth Workshop*, Ablex Publishing Co., pp. 137-161, Dec. 1993.

"Some Strategies of Reuse in an Object-Oriented Programming Environment" (with B.Lange), *Proceedings of ACM Conference on Human Factors in Computing Systems* (CHI '89), Austin, TX, May 1989, pp. 23-35.

"PROVIDE—A Process Visualization and Debugging Environment," *IEEE Transactions on Software Engineering*, Vol. 17, No. 6, pp. 849-857, June 1988. (Reprinted in E. Glinert, ed., *Visual Programming Environments*, IEEE Press, pp. 95-103, 1990.)

COLLABORATORS DURING PAST 48 MONTHS

Tom DeFanti, Tom Moher, Mark Gillingham, Robert Grossman, UIC; Robert Kenyon, UIC; David Naylor, UIC; Lewis Sadler, UIC; Paul Wilson, University of Texas at Austin; Joseph Dvorak, Motorola Corporation; Thomas Muscarello, DePaul University

GRADUATE STUDENTS

Ph.D. students (5): Victor Dirda, Thomas Muscarello, Paul Wilson, Michael Lam, Joseph Dvorak.
M.S. students (14)

GRADUATE ADVISOR: William B. Thompson

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Stellan Ohlsson's research interests revolve around the basic mechanisms of cognitive change. In past work, he has published extensively on the computational modeling of cognitive skill acquisition, with emphasis on the learning from error andon the interaction between deep domain knowledge and skills. His current research aims for a theory of the acquisition of abstract, complex ideas, particularly ideas that form the basis for scientific explanations. He also writes about the interface between cognitive theory and educational practice, sudden insight during problem solving and about the history and philosophy of cognitive science.

CURRENT POSITION

Associate Professor of Psychology, Department of Psychology, University of Illinois at Chicago (UIC).

PREVIOUS POSITIONS

Senior Scientist, Learning Research and Development Center (LRDC), University of Pittsburgh, Pittsburgh, PA 15260. April 1992 - December, 1995. (Reference: Prof. Lauren Resnick, Co-Director. Secretary Pat Stanton. Phone [412] 624-7485.)

Research Scientist, Learning Research and Development Center, University of Pittsburgh, January 1985 to March 1992.

Research Associate, October 1983 through October 1984. The Robotics Institute, Carnegie-Mellon University.

Post-Doctoral Fellow in the Cognitive Science Group at the Uppsala Programming Methodology and Artificial Intelligence Laboratory (UPMAIL), at the University of Uppsala, 1981 through September 1983.

EDUCATION

Filosofie doktorsexamen (Ph. D.), Department of Psychology, University of Stockholm, 1980. Dissertation: "Competence and strategy in reasoning with common spatial concepts."

Visiting graduate student at Carnegie-Mellon University in Pittsburgh, October 1978 through February 1979.

Visiting graduate student at the Center for Human Information Processing, University of California at San Diego, September, 1978.

Filosofie kandidatexamen (M. S.), University of Stockholm, 1972. Majors: Psychology and Philosophy. Minor: Mathematics.

PUBLICATIONS RELATED TO PROPOSED PROJECT

Ohlsson, S. (1996). Learning from performance errors. Psychological Review, 103, pp. 241-262.

Ohlsson, S. (1993) Abstract schemas. Educational Psychologist, 28(1), 51-66.

Ohlsson, S. (1992) The cognitive skill of theory articulation: A neglected aspect of science education? Science & Education, 1(2), 181-192.

Ohlsson, S., & Lehtinen, E. (in press). The role of abstraction in the assembly of complex ideas. International Journal of Educational Research..

Ohlsson, S., & Rees, E. (1991) The function of conceptual understanding in the learning of arithmetic procedures. Cognition & Instruction, 8(2), pp. 103-179.

OTHER SIGNIFICANT PUBLICATIONS

Buchanan, B., Moore, J., Carenini, G., Forsythe, D., Ohlsson, S., & D., Banks, G. (1995). An intelligent interactive system for delivering individualized information to patients. Artificial Intelligence in Medicine, 7, 117-154

Ohlsson, S. (1993) The impact of cognitive theory on the practice of courseware authoring. Journal of Computer Assisted Learning, 9, 194-221.

Ohlsson, S., Ernst, A., & Rees, E. (1992) The cognitive complexity of doing and learning arithmetic. Journal for Research in Mathematics Education, 23(5), 441-467.

Schooler, J., Ohlsson, S., & Brooks, K. (1993) Thoughts beyond words: When verbalization overshadows insight. Journal of Experimental Psychology: General, 122(2), 166-183.

VanLehn, K., Ohlsson, S., & Nason, R. (1994) Applications of simulated students: An exploration. Journal of Artificial Intelligence and Education, 5(2), 135-175.

COLLABORATORS DURING PAST 48 MONTHS

Tom DeFanti, Tom Moher, Andy Johnson, Mark Gillingham

GRADUATE STUDENTS

None. (Held a full-time research position until last year; this position was not compatible with serving as thesis advisor.)

GRADUATE AND POSTDOCTORAL ADVISORS

Professor Yvonne Waern, at Linkoping University, Linkoping, Sweden.

BIOGRAPHICAL SKETCH

Provide the following information for the senior personnel on the project.Begin with the Principal Investigator/Project Director (PI/PD).
DO NOT EXCEED 2 PAGES

A. Vitae, listing professional and academic essentials and mailing address.
B. List up to 5 publications most closely related to the proposed project and up to 5 other significant publications, including those being printed. Patent, copyrights, or software systems developed may be substituted for publications. Do not include additional lists of publications, invited lectures, etc. Only the list of up 10 will be used in merit review.
C. A list of persons, other than those cited in the publication list, who have collaborated on a project or a book, article, report, or paper within the last 48 months, including collaborators on this proposal. If there are no other collaborators, please indicate so.
D. A list of the names of graduate students with whom this individual has had an association as thesis advisor and postdoctoral scholar sponsored by this individual over the past five years, with a summary of the total numbers of graduate students advised and postdoctoral scholars sponsored.
E. The names of this individual's own graduate and postdoctoral advisors.

The information in C, D, and E is used to help identify potential conflicts or bias in the selection of reviewers.

Mark Gillingham

Curriculum, Instruction, and Evaluation
College of Education
University of Illinois at Chicago
ECSW 1234
1040 W. Harrison (M/C 147)
Chicago IL 60607
312.413.1280 (voice)
312.996-6400 (fax)
markgill@uic.edu

Mark Gillingham studies and supports teachers and students who use technology and the internet. Since graduating from the University of Wisconsin, he has developed graduate technology programs at the University of Maryland, infused technology in a teacher preparation program at Washington State University, and was Co-Director of the Technology Exploration Center at Michigan State University. Currently, Gillingham is responsible for infusing technology in the teacher preparation programs in the College of Education at UIC with help from a state grant: Advanced Learning Technologies in Higher Education.

Gillingham is co-advisor for the Tao of Technology in Education (TTE, pronounced tee), which is a student-edited journal that represents an exploration of new ways of presenting scholarly work about understanding the use of computer technology in educational settings. TTE uses the World Wide Web as its medium, but unlike other online publications, it does not simply transplant printed text into an electronic environment. Instead TTE takes advantage of the unique information presentation capabilities of the Web and strives to be qualitatively different from printed journals.

Recently funded projects include TheLearning Exchange for Teachers and Students through the InterNet (LETSNet), which helps teachers access teaching and curriculum resources on the World-Wide Web. This project funded by Ameritech follows several teachers who have been successful internet users as they tell their classroom stories. These teacher stories are supplemented by unit and lesson plans, curriculum guides, and explanations of the theory behind the lessons.

CURRENT POSITION

Adademic Professional: Instructional Technology, College of Education, UIC.

PREVIOUS POSITIONS

1994-1996 Academic Specialist and Co-Director, Technology Exploration Center, College of Education, Michigan State University.
1989-1994 Assistant Professor, Department of Elementary and Secondary Education, Washington State University.
1984-1989 Assistant Professor, Department of Curriculum and Instruction, University of Maryland, College Park

EDUCATION

Ph.D., Early Childhood Education, University of Wisconsin, Madison, WI, 1984
M.S., Child Development, Iowa State University, Ames, IA, 1978
B.S., Child Psychology, University of Minnesota, Mpls, MN,1976

PUBLICATIONS RELATED TO PROPOSED PROJECT

Internet Communication in Six Classrooms: Conversations Across Time, Space, and Culture. (with Ruth Garner), (1996). Mahwah, NJ: Erlbaum.

Comprehending Electronic Text. In Herre van Oostendorp, (Ed.), Cognitive aspects of electronic text processing. (1996). Norwood, NJ: Ablex.

Effects of question complexity and reader strategies on adults' hypertext comprehension. Journal of Research on Computing in Education, 26, 1-15, (1993).

The MSU Technology Exploration Center: Design principles for a collaborative learning environment.. (with Margaret Ropp, & Patrick Dickson, (1995, December 2). Paper presented at Tel Ed '95, Ft. Lauderdale.

Evaluation of a Website for K-12 Teachers: The LETSNet Project.. (with Andrew Topper, Nicole Ellefson & Valerie Worthington) (1996, December 7). Paper presented at Tel Ed '96, Tampa FL.

OTHER SIGNIFICANT PUBLICATIONS

Topper, A.G., Elefson, N.C., Worthington, V.L. & Gillingham, M.G. (in press). Teacher Professional Development on the World-Wide Web: The LETSNet Web site and teacher learning. Journal of Technology in Teacher Education.

Garner, R., & Gillingham, M.G. (in press). New voices: The Internet communication of high school kids who (usually) won't write. The High School Journal.

Garner, R., & Gillingham, M.G. (in press). The Internet in the classroom: Is it the end of transmission-oriented pedagogy? In D. Reinking, M. McKenna, L. Labbo, & R. Kieffer (Eds.), Literacy for the 21st century: Technological transformations in a post-typographic world. Mahwah, NJ: Erlbaum.

Gillingham, M.G., Young, M, & Kulikowich, J. (1994). Enticing teachers to expand notions of classroom text to include non-linear text. In R. Garner and P.A. Alexander, (Eds), Beliefs about text and Instruction with text. Hillsdale, NJ: Erlbaum.

Gillingham, M.G. & Garner, R. (1992). Readers' comprehension of mazes embedded in expository texts. Journal of Educational Research, 85, 234-241.

COLLABORATORS DURING PAST 48 MONTHS

Tom DeFanti, Tom Moher, Andy Johnson, Stellan Ohlsson, Maria Roussos,Patrick Dickson, Michigan State University (MSU); Carol Sue Englert,MSU; Ruth Garner, UIC; Jim Levin, Michael Waugh, University of Illinois at Urbana/Champaign, Allan Cook, University of Illinois at Springfield

GRADUATE STUDENTS

None since 1989.

GRADUATE AND POSTDOCTORAL ADVISORS

Dissertation advisor: Gary Glen Price, University of Wisconsin-Madison

BIOGRAPHICAL SKETCH

Provide the following information for the senior personnel on the project.Begin with the Principal Investigator/Project Director (PI/PD).
DO NOT EXCEED 2 PAGES

A. Vitae, listing professional and academic essentials and mailing address.
B. List up to 5 publications most closely related to the proposed project and up to 5 other significant publications, including those being printed. Patent, copyrights, or software systems developed may be substituted for publications. Do not include additional lists of publications, invited lectures, etc. Only the list of up 10 will be used in merit review.
C. A list of persons, other than those cited in the publication list, who have collaborated on a project or a book, article, report, or paper within the last 48 months, including collaborators on this proposal. If there are no other collaborators, please indicate so.
D. A list of the names of graduate students with whom this individual has had an association as thesis advisor and postdoctoral scholar sponsored by this individual over the past five years, with a summary of the total numbers of graduate students advised and postdoctoral scholars sponsored.
E. The names of this individual's own graduate and postdoctoral advisors.

The information in C, D, and E is used to help identify potential conflicts or bias in the selection of reviewers.

Maria Roussos

Electronic Visualization Laboratory
University of Illinois at Chicago
851 S. Morgan St., Room 1120 SEO
Chicago, IL 60607-7053

(312) 996-3002
(312) 413-7585 fax
mroussos@eecs.uic.edu

Maria Roussos is a graduate researcher at the Electronic Visualization Laboratory at the University of Illinois at Chicago, completing a MS in Computer Science and a Master of Fine Arts in Electronic Visualization. Her research interests focus on the design and evaluation of virtual reality in K-12 education. She is also interested in improving metaphors for Human-Computer Interaction, interactive computer art, and the design of educational exhibits for museums.

CURRENT POSITION

Research Assistant & Graduate student, Electronic Visualization Laboratory, University of Illinois at Chicago (UIC).

PREVIOUS POSITIONS

Production Coordinator of the File Room project, Electronic Visualization Laboratory and Randolph Street Gallery, Chicago IL. January 1994 - September 1994.

Research Scientist, Center for Economics Research, Athens University of Economics, Athens Greece. December 1992 - July 1993. Kleidarithmos LTD., Athens Greece. January 1992 - May 1992 Publications Organizer, H.A. Samouhos Publications LTD. - PCWORLD magazine, Athens Greece. September 1990 - January 1992.

EDUCATION

Master of Science (M.Sc.) Department of Electrical Engineering and Computer Science. University of Illinois at Chicago, 1997. Thesis: "Issues in the Design and Evaluation of a Virtual Reality Learning Environment."

Master of Fine Arts in Electronic Visualization, Department of Art and Design, University of Illinois at Chicago, (expected 1997).

Bachelor of Science (B.Sc.) in Information Science (Statistics, Economics, Computer Science), Athens University of Economics and Business, Athens Greece, 1992.

Diploma in History of Art and Archeology, Athens Archeological Society, School of History of Art, 1993.

PUBLICATIONS RELATED TO PROPOSED PROJECT

Roussos, M.,Johnson, A., Leigh, J., Barnes, C., Vasilakis, C., and Moher, T. The NICE project: Narrative, Immersive, Constructionist/Collaborative Environments for Learning in Virtual Reality. Proceedings of ED-MEDIA/ED-TELECOM 97, AACE, June 1997.

Roussos, M., Johnson, A., Leigh, J., Vasilakis, C., Barnes, C., and Moher, T. NICE: Combining Constructionism, Narrative, and Collaboration in a Virtual Learning Environment. Computer Graphics: Proceedings of ACM SIGGRAPH '97. New York: ACM SIGGRAPH, 1997.

Roussos, M.,Johnson, A., Leigh, J., Vasilakis, C., Moher, T. Constructing Collaborative Stories Within Virtual Learning Landscapes. European conference on A.I. in Education. Lisbon, Portugal: Colibri Editions, 1996, pp 129-135.

OTHER SIGNIFICANT PUBLICATIONS

Roussos,M. and Brenner, P. An Interactive Computer Project Addressing Cultural Censorship. Proceedings of 2nd WWW Conference, Chicago IL, October 1994.

Roussou,M. Art and Censorship on the Internet. Oksi Magazine, a quaterly publication on Computer Music & the Electronic Arts, Athens, Greece, October 1995 issue.

COLLABORATORS DURING PAST 48 MONTHS

Tom DeFanti, Mark Gillingham, Stellan Ohlsson

GRADUATE AND POSTDOCTORAL ADVISORS

M.S. thesis advisor: Tom DeFanti

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Thomas A DeFanti

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Thomas A DeFanti - PI**	**0.00**	**0.50**	**0.00**	$ **0**	$
2. **Mark Gillingham - Sr. Personnel**	**0.00**	**0.00**	**2.00**	**11,324**	
3. **Andrew E Johnson - Co-PI**	**0.00**	**0.00**	**2.00**	**12,480**	
4. **Thomas G Moher - Co-PI**	**0.00**	**0.00**	**2.00**	**18,124**	
5. **Stellan Ohlsson - Co-PI**	**0.00**	**0.00**	**2.00**	**15,235**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	**0.00**	**9.00**	**3.00**	**50,000**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**9.50**	**11.00**	**107,163**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**7**) GRADUATE STUDENTS				**111,223**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**218,386**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**23,451**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**241,837**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				**12,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
(**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**20,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**20,000**	
TOTAL OTHER DIRECT COSTS				**40,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**293,837**	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) **% of MTDC (Rate: 50.00, Base: 293837) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS				**191,407**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**485,244**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **485,244**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
Thomas A DeFanti				
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Roussos, Maria - Sr. Personnel	0.00	9.00	3.00	50000

**** I- Indirect Costs**
RA Tuition Remission (Rate: 40.00, Base 111223)

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Thomas A DeFanti

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Thomas A DeFanti - PI**	**0.00**	**0.50**	**0.00**	$ **0**	$
2. **Mark Gillingham - Sr. Personnel**	**0.00**	**0.00**	**2.00**	**11,777**	
3. **Andrew E Johnson - Co-PI**	**0.00**	**0.00**	**2.00**	**12,979**	
4. **Thomas G Moher - Co-PI**	**0.00**	**0.00**	**2.00**	**18,849**	
5. **Stellan Ohlsson - Co-PI**	**0.00**	**0.00**	**2.00**	**15,844**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	**0.00**	**9.00**	**3.00**	**52,000**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**9.50**	**11.00**	**111,449**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**7**) GRADUATE STUDENTS				**114,560**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**226,009**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**24,363**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**250,372**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				**12,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
(**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**15,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**15,000**	
TOTAL OTHER DIRECT COSTS				**30,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**292,372**	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) **% of MTDC (Rate: 50.00, Base: 292372) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS				**192,010**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**484,382**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **484,382**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*
Thomas A DeFanti

DATE

ORG. REP. TYPED NAME & SIGNATURE*

DATE

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Roussos, Maria - Sr. Personnel	0.00	9.00	3.00	52000

**** I- Indirect Costs**
RA Tuition Remission (Rate: 40.00, Base 114560)

SUMMARY PROPOSAL BUDGET

YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Thomas A DeFanti

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Thomas A DeFanti - PI**	**0.00**	**0.50**	**0.00**	$ **0**	$
2. **Mark Gillingham - Sr. Personnel**	**0.00**	**0.00**	**2.00**	**12,248**	
3. **Andrew E Johnson - Co-PI**	**0.00**	**0.00**	**2.00**	**13,498**	
4. **Thomas G Moher - Co-PI**	**0.00**	**0.00**	**2.00**	**19,603**	
5. **Stellan Ohlsson - Co-PI**	**0.00**	**0.00**	**2.00**	**16,478**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	**0.00**	**9.00**	**3.00**	**54,080**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**9.50**	**11.00**	**115,907**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**7**) GRADUATE STUDENTS				**117,997**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**233,904**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**25,311**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**259,215**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				**12,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
(**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**15,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**15,000**	
TOTAL OTHER DIRECT COSTS				**30,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**301,215**	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) **% of MTDC (Rate: 50.00, Base: 301215) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS				**197,806**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**499,021**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **499,021**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*
Thomas A DeFanti

DATE

ORG. REP. TYPED NAME & SIGNATURE*

DATE

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 3

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Roussos, Maria - Sr. Personnel	**0.00**	**9.00**	**3.00**	**54080**

**** I- Indirect Costs**
RA Tuition Remission (Rate: 40.00, Base 117997)

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Thomas A DeFanti

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Thomas A DeFanti - PI**	**0.00**	**1.50**	**0.00**	$ **0**	$
2. **Mark Gillingham - Sr. Personnel**	**0.00**	**0.00**	**6.00**	**35,349**	
3. **Andrew E Johnson - Co-PI**	**0.00**	**0.00**	**6.00**	**38,957**	
4. **Thomas G Moher - Co-PI**	**0.00**	**0.00**	**6.00**	**56,576**	
5. **Stellan Ohlsson - Co-PI**	**0.00**	**0.00**	**6.00**	**47,557**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	**0.00**	**27.00**	**9.00**	**156,080**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**28.50**	**33.00**	**334,519**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**21**) GRADUATE STUDENTS				**343,780**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**678,299**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**73,125**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**751,424**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				**36,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
(**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**50,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**50,000**	
TOTAL OTHER DIRECT COSTS				**100,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**887,424**	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				**581,224**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**1,468,648**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **1,468,648**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY
Thomas A DeFanti		INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Thomas DeFanti**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **UIC High Performance Network Connections to vBNS and the Internet Through a Uniform Campus Procedure**

Source of Support: **National Science Foundation**

Total Award Amount: $ **354,000** Total Award Period Covered: **07/01/96 - 06/30/98**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: Summ: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Development of Instrumentation for Shared Virtual Prototyping: The ImmersaDesk and the NII/Wall**

Source of Support: **National Science Foundation**

Total Award Amount: $ **814,000** Total Award Period Covered: **09/01/95 - 08/31/98**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: **1.00** Summ:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **A National Scale Distributed Computing Environment**

Source of Support: **National Science Foundation**

Total Award Amount: $ **790,500** Total Award Period Covered: **08/01/95 - 07/31/98**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: **1.00** Summ:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Quantitative Assessment of Transfer of Training in the CAVE Virtual Environment and Its Relevance to the National Information Infrastructure (NII)**

Source of Support: **National Science Foundation**

Total Award Amount: $ **375,000** Total Award Period Covered: **08/01/95 - 07/31/98**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: Summ: **1.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Remote Manufacturing Design Support Using Virtual Reality**

Source of Support: **National Science Foundation**

Total Award Amount: $ **434,438** Total Award Period Covered: **06/01/95 - 05/31/98**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: **0.50** Summ:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Thomas DeFanti**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Virtual Reality Alliance: Augmenting and Complementing NII MetaCenter Activities (MetaCenter Regional Alliance)**

Source of Support: **National Science Foundation**

Total Award Amount: $ **1,285,736** Total Award Period Covered: **10/01/94 - 09/30/97**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: **2.00** Summ:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **National Computational Science Alliance**

Source of Support: **National Science Foundation**

Total Award Amount: $**216,327,580** Total Award Period Covered: **10/01/97 - 09/30/02**

Location of Project: **University of Illinois at Urbana-Champaign**

Person-Months Per Year Committed to the Project. Cal: Acad: **2.00** Summ:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **The Chicago STAR TAP Science and Technology and Research Transit Access Point**

Source of Support: **National Science Foundation**

Total Award Amount: $ **1,261,000** Total Award Period Covered: **05/01/97 - 04/30/00**

Location of Project: **University of Illinois at Chicago & Urbana-Champaign**

Person-Months Per Year Committed to the Project. Cal: Acad: Summ: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **A CAVE for Science and Education Applications (Supplement to NSF CDA9303433)**

Source of Support: **National Science Foundation**

Total Award Amount: $ **300,000** Total Award Period Covered: **03/01/97 - 01/31/99**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal: Acad: **1.00** Summ:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Virtual Director: A Virtual Reality Method for Steering Scientific Visualizations**

Source of Support: **National Science Foundation**

Total Award Amount: $ **400,000** Total Award Period Covered: **07/01/97 - 06/30/00**

Location of Project: **University of Illinois at Chicago & Urbana-Champaign**

Person-Months Per Year Committed to the Project. Cal: Acad: **1.00** Summ:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Thomas Moher**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **GTECH/UIC Consortium**

Source of Support: **GTECH Corporation**

Total Award Amount: $ **1,650,000** Total Award Period Covered: **09/01/90 - 12/31/97**

Location of Project: **University of Illinois at Chicago**

Person-Months Per Year Committed to the Project. Cal:**3.00** Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory:

Clinical:

Animal:

Computer:

Office:

Other: _____

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

All equipment is located within or directly proximate to the Electronics Visualization Laboratory. Workstations are available on a first-come, first-served basis, but there is sufficient capacity in the present environment to support this proposal.

The CAVEs, ImmersaDesks, and Infinity Wall (see description in proposal body) are available on a scheduled basis, but EVL is

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

This project will benefit markedly from the equipment, space, and staff infrastructure already in place in the Electronic Visualization Laboratory. In particular, maintenance support will be provided by EVL staff.

Continuation Page:

MAJOR EQUIPMENT (continued):

committed to providing ample time on these pieces of equipment. The scope of the proposed project is consistent with our CISE grant, and we will use the equipment purchased under that grant in support of this proposal.

The major pieces of equipment are:

17 SGI Indy workstations,
8 SGI Impacts,
4 SGI O2s,
1 SGI Indigo 2,
3 SGI Onyxes,
(a) 4 195Mhz R10000 CPUs and 1 Infinite Reality Engine and 256meg RAM
(b) 9 150mhz R4000 CPUS and 8 200 mhz R4000s 3 Reality Engine IIs and 512meg RAM
(c) 4 195Mhz R10000 CPUs and 2 Infinite Reality Engines and 512meg of RAM

2 CAVEs,
4 ImmersaDesks,
1 Infinity Wall,
video editing suite,
ATM/SONET switches,
and Ethernet and HIPPI local-area networks.
The ATM switch is directly connected to the vBNS and the Chicago Metropolitan Research and Education Network (MREN) via the Ameritech Chicago NAP over an OC-3c link. Funding for 622 Mbps upgrades has been awarded through the NSF Connections Program.