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**Investigating Interactive Immersive Worlds:
Assessing the relevance of computer games for
STEM learning environment design**

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The nature of contemporary scientific knowledge and practice suggests that the design of next-generation learning environments for science education should include advanced multimedia representations and modeling tools, as well as real-time interaction with peers, mentors, intelligent agents, and computational models and simulations. The most successful approximations to virtual environments with these features for a broad segment of school-age users are found today in high-end commercial computer games. I propose an initial, small-scale research project to determine in what respects interactive-immersive commercial computer games (CCGs) may offer useful guidance for the design of next-generation STEM learning environments (SLEs).

The proposed project will:

- Build a small database of screen-capture video-recordings and relevant meta-data of 1st and 2nd-year undergraduates in the sciences interacting with CCGs and SLEs over extended periods of time
- Use techniques derived from semantic discourse analysis, multimedia semiotic analysis, and usability analysis to identify design-afforded strategies by which users learn across multiple media, tools, and virtual attentional spaces on both shorter-term (minutes-to-hours) and longer (days-to-weeks) timescales
- Present to an expert advisory panel both examples of original video data and descriptive and comparative analytical findings to ground a discussion of issues of comparability and applicability of lessons learned from studying CCGs to the prospective design of future SLEs
- Respond to requests from the advisory panel for data and analysis relevant to particular questions and concerns raised in the discussions
- Prepare a report to the Foundation describing both the analytical findings and the conclusions of the advisory panel and project staff regarding applicability of the

findings to future STEM learning environment design and recommendations for further research

- Disseminate significant findings and conclusions to the science education, learning technologies, and other relevant research communities
- Train research students in applicable methods of discourse and multimedia data analysis
- Involve undergraduate volunteers in the sciences in all aspects of the project

In what sense are commercial computer gameworlds comparable to and potentially models for the science education software and computer-based learning environments (SLEs) of the future? Certainly not in their overt content or frequent emphasis on violent fantasies, but possibly in their development of interactive, immersive worlds where state-of-the-art multimedia, complex combinations of verbal and graphical representations, and intensive interactions with other users successfully engage school- and college-age students in complex cumulative learning trajectories through time and across situations. Both the nature of contemporary science and the demands of science learning require sustained engagement with, and fluent and thoughtful integration across, multiple (and increasingly dynamic) representations in a variety of media. Gameworld designers in a competitive marketplace have evolved numerous successful strategies for engaging, supporting, and scaffolding users in extremely demanding learning and performance tasks to which they voluntarily commit extraordinary amounts of personal time and effort. What can we learn from their success, not just about multimedia design principles in general, but also about how learners integrate representations, media, and experiences across time and learning events? More specifically:

1. What empirical and theoretical basis is there for deriving guiding principles for the design of next-generation STEM learning environments (SLEs) from comparisons between how users interact with current SLEs and with commercial computer gameworlds (CCGs)?
2. What is the research potential of linguistic and semiotic analysis of digital video records for investigating how users combine textual, visual-graphical, and interactive multimedia representations in learning, constructing meanings, and problem-solving in SLEs and CCG's?
3. What can we expect to learn from such digital video records about how users (students/players) integrate and cumulate sense-making activities with virtual artifacts, agents, and features of places across shorter and longer timescales in SLEs and CCG's?

Rather than beginning with the assumption that CCG's are relevant to SLE design, the project will aim to determine in what ways SLE's and CCG's are comparable or significantly different in structure, purpose, and modes of interaction with users, and how the similarities and differences bear on issues of future SLE design. Descriptive evidence,

organized around a number of specific conceptual issues described below, will be presented to an expert panel representing seasoned researchers and SLE designers and evaluators in science education, learning sciences and learning technologies, and game studies in education. The panel's arguments, conclusions, and recommendations will be presented along with the empirical findings of the project.

Multimedia Science and Multimedia Learning

Even before the recent widespread use of advanced computing technologies in scientific research, it was already the norm in scientific communication to construct complex multimodal texts which inter-connect verbal discussion, mathematical representation, and a wide variety of visual-graphical genres for data inscriptions, quantitative relationship graphs, abstract diagrams, spatial or pseudo-spatial maps, etc. (Lemke, 1998c; Roth, Bowen, & McGinn, 1999). This tradition arises from the nature of scientific practice: we study phenomena and relationships that cannot be adequately described in words alone because the semantics of natural language makes categorical distinctions rather than distinctions of degree and quantitative difference. The natural world is well-modeled by continuous variation in space and time and co-variation among a multitude of in-principle continuously variable dynamical parameters. Mathematics extends the semantics of natural language to meanings-by-degree, and visual-graphical representations in two- and three-dimensions provide appropriate 'topological' tools for representation and analysis of quantitative data, as well as for theoretical reasoning, in scientific practice (Lemke, 2002a; Lynch & Woolgar, 1990).

Moreover, it has recently become far easier to create *dynamic* visual representations in the form of animations, videos, and simulations that can image large numerical databases. Three-dimensional, dynamic data and model visualizations can be made interactively responsive to the user's exploration of changing viewpoints, parameters, and subsets of data (Brodie et al., 1992). At the same time contemporary science is also using new information technologies to construct virtual laboratories in which researchers can communicate and share data and developing models in real time, as well as interact with models and tools (Finholt, 2002). Today research groups exchange not just sets of equations and numerical data, but simulations and computational models, many of which include interactive, dynamic visualizations. The repertory of analytical and representational tools is growing in richness and complexity, and the science of the future will be understood and presented through such multimedia tools.

Alongside this picture of scientific practice, printed science textbooks are beginning to seem archaic. Print media are inherently limited as educational tools for science: they cannot show dynamic processes in time, and they cannot afford interactive exploration of data or models by students. They cannot be updated or revised quickly or cheaply. Educational software today already makes use of individual components of the multimedia world of contemporary science: videos, animations, interactive simulations, data visualizations, modeling tools, and collaborative media; but as the design of science

learning environments progresses towards the closer *integration* of all these elements, it will encounter some fundamental problems.

We lack systematic knowledge about how to combine language, mathematical symbolic representations, and the wide variety of traditional graphical media *for science learners*. Professional scientists reading scientific papers or participating in online collaboratories are a highly selected group which has been well-schooled in how to make sense of complex combinations of these elements. Science learners, on the other hand, are traditionally taught very little about how to read images, how to read them differently in relation to accompanying text, or how to translate back and forth among visual, verbal, and mathematical representations, even though the current multimedia demands of the enacted science curriculum are already extremely high for students (Lemke, 1998b). Professional scientists can rely on deep background knowledge to enable them to navigate within today's greatly enlarged repertory of dynamic, interactive, three-dimensional representations. The corresponding demands on learners only become more daunting, though the potential is great (Jakobsson, 2000). What are powerful new tools for scientists, however, may well become serious new obstacles for science learners.

To design effective next-generation multimedia learning environments for science education (SLEs), we need much better understandings of how it is possible to combine multiple media, multiple representations, multiple attentional spaces, dynamic interactivity, immersion in and navigation through virtual spaces, collaboration with others, and interaction with computational agents and tools, *for learners*. From one perspective this is a problem of understanding *sense-making processes*: how are meanings constructed by users who integrate such diverse representations in real time as part of their on-going activity? From another it is a problem in media design: how can visual and auditory, interactive and immersive media be effectively deployed to support learners who are new to using such media and tools for complex sense-making?

Learning from Gameworlds

We are not the first to encounter these problems. For the past ten years the designers of commercial video- and computer- games have been evolving successful strategies for engaging a broad segment of the school-age and older adult population in complex, immersive, interactive, three-dimensional, dynamic multimedia environments: *gameworlds* (Herz, 1996; King, 2002; Rouse & Ogden, 2001; Salen & Zimmerman, 2004, 2006). They have gone from two-dimensional to three-dimensional worlds, from text-only to comprehensively multimedia environments, from simple animations to full-motion video, from single-player to massively-multiplayer systems, from inflexible program responses to subtly contingent interaction with artificially intelligent agents, and from fixed-design worlds to persistent, user-modifiable online environments of vast complexity. Users carry out collaborative activities, with voice and text as well as visual communication; they cycle their attention rapidly among a variety of visual displays of information; they create and share logs and records of their previous trials of various strategies; they integrate audio and visual cues; they interact with objects, tools, AI-

agents, and avatars of other users; they solve seemingly endless complex problems, spend untold hours doing so, and thoroughly enjoy the effort. Indeed they pay for the privilege. According to industry data, over 50% of all Americans play computer or video games regularly, in about 70% of U.S. households (anticipated by end of 2005); 39% of players are women; 30% (on computers) to 38% (on dedicated game consoles) are under 18 years old; 239 million game software units were sold in the U.S. in 2003 (average 2 per household), for revenues of about \$7 billion, comparable to Hollywood box-office receipts of about \$8 billion (Educational Software Association, 2004).

In addition to the gameworlds as such, there are very large and active online communities of players who share information, strategies, and solutions, and smaller sub-communities who reverse engineer the logic and even the programming of the games to create new artifacts and tools that function within the gameworld, or in some cases whole new environments or new games that run under its core programming (often with the support of the original commercial designers and publishers). Even those who remain simply players form online guilds and associations, publish websites, and write substantial informational texts and game-based fictions which are shared in their communities (Black, 2004; Steinkuehler, 2004). This represents success in social learning and collaborative inquiry on a vast scale.

This success has already attracted substantial attention and funding from other institutions and government agencies with an educational mission: the U.S. Department of Defense (U.S. Army, 2002), the National Institute of Justice (BreakAway Ltd, 2004), the National Institutes of Health (Lieberman, 2001), NASA (Vision Videogames, 2005), and the Dutch government (Erisman et al., 2002) have all funded the development of game media for science and technology -related learning. NSF is currently supporting development and/or research on at least four gameworld-based online science learning communities for students: *Quest: Atlantis* (Barab, Thomas, Dodge, Carteaux, & Tuzun, in press), *Whyville* (Kafai, 2004), *Immune Attack* (FAS, 2004), and a new physics through gaming project (Cannon-Bowers, 2005). Similar work is also being supported by Britain's National Endowment for Science, Technology, and Arts (Facer, 2003; Kirriemuir & McFarlane, 2004; NESTA Futurelab, 2004).

We should be cautious, however, in reasoning from the success of commercial gameworlds to design principles for SLEs for several reasons. Many features of successful gameworld environments have been far more attractive to males than to females (though overall 40% of computer and video game players are female). This project will include studies of at least one prominent exception, *The Sims*; the non-commercial *Whyville* is another. In many cases much of the motivation for persistence in learning the complexities of commercial gameworlds comes from simulated fear and opportunities for violence. But in most of these cases, and in many other gameworlds, it also comes from the pleasures of problem-solving, social collaboration, assuming and meeting social responsibilities, exploration for its own sake, justice achieved, goals reached, creativity exercised, skills mastered, friends made, artifacts created, and adventures enjoyed (Costikyan, 2002), (Hunicke, LeBlanc, & Zubek, 2004).

Many gameworlds are by design deliberate learning environments whose content is at least as complex and detailed as that required by the STEM curriculum, and game designers have re-discovered and made good use of many research-based principles of learning theory (Gee, 2003). However, it remains to be determined whether the kinds of learning emphasized in STEM curricula, particularly abstract logical-conceptual relationships, are as amenable to the learning design strategies of CCG's as are rich, structured factual content and problem-solving in concrete, visually represented environments. This project complements 'proof-of-concept' experiments such as *Quest Atlantis* or Cannon-Bowers' project. It proposes to systematically analyze how multimedia learning strategies are similar and different in existing CCG's and SLE's, both for shorter- and longer-term learning.

Conceptual Organizing Principles

In what respects might we imagine that CCGs and SLEs or future SLEs are comparable? What kinds of evidence from analyses of students' interactions with these media is likely to be relevant to identifying significant similarities and differences that are potentially relevant to future SLE design?

The first broad organizing principle for a systematic analysis of potential comparability recognizes that both types of media present information *multimodally*, i.e. in terms of multiple representations in multiple media. Accordingly we seek digital video data that will enable us to investigate comparatively:

(Q1) How do users combine linguistic, visual-graphical, and multiple modes of representation in learning, constructing meanings, and problem-solving in SLEs and in interactive-immersive computer gameworlds?

Research on situated and distributed cognition argues convincingly in my opinion that sense-making activities depend critically on salient contextual features (Hutchins, 1995; Lave, 1988; Lave & Wenger, 1992), and my own theoretical extensions of these ideas propose that material objects and representations also play a role in the cumulation of learning across timescales (Lemke, 2000). Thus a second kind of data we seek should enable us to make comparisons with respect to a further question:

(Q2) How do users (students/players) integrate and cumulate sense-making activities with virtual artifacts, agents, and features of places across shorter and longer timescales in SLEs and interactive-immersive computer gameworlds?

These two guiding research questions embody the two corresponding grounds of potential comparability in relation to learning: multimodality and situativity. Comparability of course does not imply similarity. When comparisons are made differences will be found as well as potential similarities. Our concern here is that both similarities and differences in these two respects are highly likely on theoretical grounds

to be relevant to learning processes, and more specifically to learning in these two kinds of environments.

Moreover, they are also potentially relevant to SLE design because they concern how students make use of the affordances of the program design features (e.g. representations, integration across media, visual settings, pacing and cumulation across time) for learning. SLE designers will not choose the content to be learned, only the means provided to support learning it. CCGs and SLEs clearly differ in the content they make available for learning, but what we seek to determine in this project is whether, despite these differences,

(Q3) Do similarities in the learning-process-to-design-features relationship in these two respects (multimodality and situativity) suggest that CCG's can indeed provide useful guidelines for development of future interactive-immersive multimedia SLEs, or not?

In the course of answering this question, the project may also produce hypotheses regarding some such prospective guidelines, which would then naturally need to be tested in other research.

From Data to Evidence: Logic of the Research

The two initial organizing questions I have posed above (Q1, Q2) require an investigation of *processes*. Sense-making processes in context and integrative processes across time can be analyzed through naturalistic observations, but more effectively when these are also recorded as rich data-types, particularly digital video (with interleaved audio). User interactions with computer-based multimedia, whether for SLEs or in gameworlds, need to be recorded to video, along with the actions and speech of the user and a logfile of keystrokes, mouseclicks, etc. Standard procedures and software for such data collection already exist in the field of software usability studies (Noldus Information Technology, 2003; Pagulayan, Keeker, Wixon, Ramero, & Fuller, 2003; Techsmith Inc, 2004).

In addition to real-time process recording, it is important to understand the meaning and importance of actions taken and users' reasoning. Prompting users for simultaneous think-aloud commentary may interfere with effective or naturalistic use of SLEs and particularly gameworld software. The project will investigate to what extent a think-aloud procedure can succeed both directly and also indirectly (e.g. through recording dialogue between the user and a co-present peer). In addition, we will conduct formal pre- and post-session interviews, also recorded to digital video. Preliminary interview protocols have already been constructed (see below). Most post-session interviews will include retrospective review of recorded video ("stimulated recall"); some will occur immediately after sessions and others after longer periods of time and even after subsequent sessions using the same software. We need to understand not just what is done and what is learned immediately after a session, but also what is carried over to later sessions, including much later ones (weeks to months).

User activity needs to be analyzed in relation to both the specific multimedia affordances of the software environments and the two principled grounds of comparability for learning. We will construct a Features Inventory (FI) profile for each software module used, and the research team will identify and mark video episodes likely to be most relevant to the two organizing questions according to the criteria defined in an Event Protocol (EP). Preliminary versions of both the FI and the EP have already been created (see below).

Relevant episodes from recorded sessions will be transcribed, annotated and incorporated, along with interview transcripts and links to video data, in a multimedia relational database designed to support analysis of common themes and patterns and generation of hypotheses (Atlas.ti Scientific Software, 2004). Episodes will be selected for their relevance to Q1 and Q2 as elaborated in the EP, rather than for their being representative of a particular SLE or gameworld. We will not be investigating these software modules as such, but rather user interactions with them that meet specific criteria (e.g. integrating 3 or more information sources from different media). Later in the project, episodes will be selected primarily to elaborate and test developing hypotheses, provide possible disconfirming evidence, and make specific comparisons between similar phenomena in SLEs and in gameworld environments. (See discussion of the Event Protocol below.) In particular, we will seek in the second year to select episodes providing evidence for the kinds of comparability or non-comparability identified initially by the expert panel.

Initial data collection will be followed by a first period of analysis in order to generate specific hypotheses or respond to specific judgments or concerns by the expert panel, to be actively pursued during a second period of data collection (see Project Timetable). We will also regularly *reserve* portions of the data archive that will not be analyzed immediately, but will become available to further check evolving hypotheses at later stages of the project when no new data is being collected. This allows us to test data-driven hypotheses against data that were not included in their formulation.

For the comparability issues defined by both Q1 and Q2, the principal method of data analysis will be Semantic Discourse Analysis (Halliday & Matthiessen, 1999; Lemke, 1990, 1998a) for verbal-textual data and Multimedia Semiotic Analysis (Kress & van Leeuwen, 1996, 2001; Lemke, 2002b; O'Halloran, 2004) to link it to visual and other media. SDA is by now a well-established procedure, and the proposed P.I. is a recognized leader in this field. MSA is in a relatively earlier stage of its development, but is the only appropriate tool, in large part because it generalizes the categories and logic of SDA and therefore allows analysis of how sense-making can integrate (1) content, (2) interactional, and (3) organizational meanings across multiple representations. This method has already been used successfully in the analysis of interactive, multimedia NASA websites (Lemke, 2002b) and is being extended to video (Lemke, in press). Using MSA we will examine, for example, how users interpret images, animations, or video in relation to accompanying text (and vice versa) and how their use of virtual artifacts or tools is guided by verbal and spatial cues. For Q1 we will mainly be analyzing relatively short

recorded episodes (5-10 minutes) in rich detail. For Q2 we will be looking for repeated patterns, strategies, and means of cumulating learning over much longer periods.

The theoretical framework for these analyses is Halliday's functional model of linguistic sense-making, extended to multimedia (references as above). The model posits three functional dimensions (sense-making about content, interactional addressivity and evaluative stance, and local and global textual organization and coherence) along which each medium or information source may contribute. In addition, contributions along each dimension may cross-contextualize one another, so that, for instance, construing an image and a text as a figure-and-caption unit (organizational function) allows us to re-interpret the content of the image through the content of the text. The further specification of this model, for the multimedia genres of SLEs and CCGs, is a subsidiary objective of this research project. It will considerably enrich our repertoire of basic conceptual models for multimedia sense-making (Ainsworth, 1999; Mayer, 2001, 2005; Rogers & Scaife, 1998) by adding semiotic considerations consistent with established principles in functional linguistics. These same principles and the discourse-specific version of the theoretical model, were the basis of the success of my earlier "Talking Science" project (Lemke, 1990).

For Q2 we will be looking across longer timescales of learning, identifying how sense-making patterns observed in early sessions compare to those following additional hours of use of the same software by the same user, progressively from an hour or two of additional use up to a limit of perhaps 20-40 hours, over a period of weeks. We will also compare users who are already very familiar with the software at their first project session to those who are entirely new to it. We will be looking to identify how past experience is specifically made use of in later sessions and how this facilitates further learning and success. We will be testing the hypothesis that both virtual artifacts and offline notes and records play a critical role in cumulating learning across sessions widely separated in time, and we will be looking to identify patterns of using such tools for longer-timescale integration. This hypothesis grows out of a theoretical model (Lemke, 2000) based in neo-Vygotskian theories of learning (Cole, 1996; Engeström, 1987), combined with observations of the relevance of timescale hierarchies to learning in complex systems (Lemke & Sabelli, in press).

For Q3, our ultimate project objective, we will be making systematic comparisons between SLEs and gameworld environments across the data relevant to Q1 and Q2. We will present to our expert panel data and analyses that construe that data as presenting the most salient similarities and differences we have found on each of the two grounds of expected comparability. We will ask for the panelists judgments regarding the significance of both similarities and differences for the potential relevance of CCG design features for future STEM learning environments. We will also ask what additional kinds of similarities or differences they would consider highly relevant, and in the second phase of the project, we will seek to identify evidence of these as well as possible disconfirming evidence for significant, already identified similarities and differences.

Numerous theoretical arguments for the relevance of interactive-immersive multimedia gameworlds to learning in complex domains have been made (Barab et al., in press; de Castell & Jenson, 2004; Dede, Ketelhut, & Ruess, 2002; Fuchs & Eckermann, 2001; Gee, 2003; Herz, 2002; Holland, Jenkins, & Squire, 2003; Squire, 2003). We will also be asking the expert panel to articulate the theoretical grounds for saying that particular kinds of identified or hypothesized similarities and differences make it more or less likely that design features of CCG's could be adapted effectively for future STEM learning environments.

Research Procedures: Details

Expert Advisory Panel and Consultants

As described throughout this proposal the project's expert advisory panel will play a key role in directing the research and analysis toward critical issues and making judgments regarding the relevance of similarities and differences between student interaction and learning with SLEs vs CCGs. Enthusiastic agreements to participate (see Supplementary Documents) have been obtained from:

James Paul Gee, Morgridge Professor in Education and Learning Sciences, University of Wisconsin; expertise in linguistics, discourse analysis, game studies and learning

Susan R. Goldman, Distinguished Professor of Psychology, University of Illinois – Chicago; expertise in learning theory, cognitive science, learning technology

Paul Horwitz, Senior Scientist, Concord Consortium; expertise in physics, STEM learning environment design, development and evaluation (*GenScope*, *Biologica*, others)

Yasmin B. Kafai, Associate Professor of Learning and Instruction, UCLA; expertise in analysis of game design and learning, learning technologies

Janet Kolodner, Professor of Computing and Cognitive Science, Georgia Institute of Technology; Editor, *Journal of the Learning Sciences*; expertise in computer science, learning technologies, learning sciences

In addition, expertise in game design will be contracted on a consultant basis with associates of **GameLab**, Inc., New York, the firm of **Eric Zimmerman**, leading game designer and game design theorist.

Selecting SLEs, CCGs, and User-Participants

In the first months of the project we will identify 6-8 interactive, immersive digital gameworlds and 6-8 examples of high-quality multimedia science education software, which meet as many as possible of the following criteria, designed to insure that they provide affordances which will support investigation of the research questions and particularly the phenomena in the Event Protocol (below):

Science Education Software (SLEs):

Primary criteria:

- Multiple media: video and/or animation, complex graphical information displays, text and/or voice, sound effects
- Interactive: displays and/or affordances change in response to user input/actions
- Simulations: presents simulations of natural phenomena with user-variable parameters
- Three-dimensional: includes some displays representing 3-dimensions
- Immersive/navigable spaces: User viewpoint can move in display space
- Hyperlinked: significant linking of information across display screens
- Requires significant integration of information across source media or display genres

Secondary criteria:

- Displays can be rotated or viewed in three dimensions by user
- User can interact with software agents

Digital Gameworlds (CCGs):

Primary criteria

- Creates a 3-dimensional world that is navigable from the player/user point of view
- Evokes a sense of immersion or presence in the gameworld during primary play activity
- Makes significant use of dynamical media: scenes change in time through animation, video, or agent/object action and movement
- Highly interactive: scenes and affordances change in direct response to user/player action
- Media spaces: navigable spaces contain interactive semiotic objects

Secondary criteria

- Includes significant use of written and/or spoken language
- Response “engine” includes realistic or semi-realistic physics
- Includes secondary screen and interfaces with complex graphical information
- Requires integration of information cues from more than one semiotic medium
- Affords opportunities for records of past events that persist on various timescales to be made by players or made automatically

Sample SLEs – SRI *ChemSense Studio*, UIUC *Biology Student Workbench* and *ChemViz*, SDSC *TIE Project*, UGa *Virtual Solar System & Virtual Exploratorium*, *Quest: Atlantis*, *Model-IT*, Concord *BioLogica & Molecular Workbench*, NWU *GEODE/WorldWatcher*, Tom Snyder *Great Ocean Rescue & Rainforest Rescue*; TERC *Zoombinis Island Odyssey*, CalTech *Whyville*, NASA *SpaceStationSIM*, NESTA *Racing Academy*

Sample CCGs – *The Sims & The Sims 2* (with expansions); *Sid Meier’s Civilization III & IV*; *America’s Army*; *DeusEx*; *Black & White I & II*; *Half-Life 2*; *Prince of Persia: Sands of Time*; *Baldur’s Gate* (series); *Dungeon Siege*; *Star Wars: Knights of the Old Republic*; *Grand Theft Auto* (series)

The software environments actually selected will be comparable in features and quality to the representative examples listed. The SLEs will for the most part be selected from among those supported in recent years by NSF, including those affiliated with the EOT-PACI consortium (Education, Outreach, & Training Partnership for Advanced Computational Infrastructure, www.eot.org : *Projects*) and others listed in the archive of the CILT-TELS Design Principles Database (<http://www.design-principles.org/dp/index.php>). The CCGs will be primarily selected from commercially successful games, popular with players of secondary-school and college age. New CCGs and revisions or additions to major franchises and series will be considered during the first half of the project, as will new SLEs that may become available and meet a significant number of the selection criteria.

We will also be seeking to match our user-participants with the range of SLE and CCG software selected to insure (a) user familiarity with the pre-requisite science content of the SLEs and in some cases varying degrees of prior experience with a particular SLE; (b) a range of degrees of prior experience with gameworld genres and interfaces, and in some cases with particular gameworlds. Because the research focus is on basic sense-making processes, we will recruit undergraduate students, both science- and non-science majors, particularly in their first two years, leaving to later studies the question of how much they may differ from secondary-school age science learners in these respects. Our purpose here is not to teach or assess new science content knowledge or multimedia learning skills, but rather to investigate how students who already possess some relevant experience with SLEs and CCGs employ their sense-making skills in these different environments. All user-participants will record sessions with both SLEs and CCGs (usually with two of each).

In Year 1, six participants will each record interviews and user sessions with two SLEs and two CCGs. Initial experience and data will assist in finalizing selection of the software, testing the recording, transcribing, and database systems, and refining the Features Inventory, Event Protocol, and Interview Protocols. For each participant on each SLE or CCG, we will record a minimum of six hours of screen-capture digital video: the initial two hours and two two-hour segments representing midpoints and endpoints in their cumulative experience with a program. This will produce a core videobase of 144 hours, from which particular episodes meeting the EP criteria and/or addressing key issues raised by the expert panel will be selected for detailed analysis.

In Year 2, some additional user sessions will be recorded in response to expert panel issues, the role of the undergraduate participants will be to assist in the data analysis and interpretation process, bringing their user experience to the research team. (The term “user-participants” here emphasizes a more active involvement than the term “subjects”; it does not refer to the NSF budget category for participant costs/support.) We will make every effort to recruit a diverse cohort of user-participants, including participation by students from under-represented groups. More detail regarding project activities is given below in the Project Schedule.

Features Inventory, Event and Interview Protocols

For each SLE or gameworld application to be used in the study, the P.I. and graduate research assistants will first complete a formal *Features Inventory* (FI). This will identify the features that are likely to produce user experiences relevant to the project research questions. Examples of some items from the preliminary *Features Inventory* include:

Types of learning afforded; types and integration of media; user interface; types of user actions in-game/SLE; persistent user effects; functions of multiple frames and auxiliary screens; pacing and timing; spatial layout (2D and 3D) and navigation; hyperlinks; sources of motivation and interest; narrative or logical continuity; etc. (16 categories total in current version)

The FI profiles will guide project staff in observing and reviewing video records of sessions with the SLEs and gameworlds. The particular kinds of events to be noted for further analysis will be defined by the *Event Protocol*; a preliminary version includes event types such as:

Uses linguistic information to decode visual display; integrates three or more types of linguistic and/or visual information; prior information repeated; engages with animations or video; engages with interactive-responsive features (e.g. simulation); interacts with elements of a virtual space by means of a tool, agent, or artifact; shifts attention repeatedly between two information sources; creates or uses persistent features in the software environment; etc. (18 event-types in current draft)

In addition, we will interview user-participants both before (regarding relevant prior background) and after each session, guided by three *Interview Protocols* which will include items such as:

- What features did you find most difficult or frustrating to use?
 - Do you think you learned very much in this session about [the science topic]? What?
 - Can you describe to me what you were doing here? (reviewing video)
 - If you could change either the graphical display or the text to make it clearer, what would you change?
 - Do you feel under pressure of time here? Why or why not?
 - How useful to you at this point are the [dynamic elements, e.g. animations, video, simulations]?
 - What choices among [actions/tools] do you have at this point?
 - How was your action here affected by what you did or what happened earlier?
 - Were you working toward a goal at this point? What was your strategy?
- (20 questions in post-session interview, varying with type of SLE or CCG)

There will normally be an intake interview for new user-participants, pre-session interviews for each new SLE or CCG experience, an immediate post-session interview,

and a more in-depth retrospective interview, viewing the video records of selected episodes from the user's session.

Project Data Archive and Digital Video Technology

Commercial scan converters (e.g. Canopus *TwinPact100*) can record screen displays and computer-generated audio directly to AVI digital video files (uncompressed), which can be stored by a FireWire link directly to an external hard-drive (e.g. via Focus Enhancements *FireStore FS-1* and 250GB drive). These files will be transferred initially to DVD-ROM for archiving, but reliable video archival storage beyond 5 years requires transfer to magnetic tape (SONY AIT). A digital video mixing board (e.g. Focus Enhancements *MX4-DV*) can integrate into the AVI file (as PIP, picture-in-picture) a second audio-video signal from a videocamera and microphone recording the user-participant's actions and speech. (Options in the *MORAE* system from Techsmith allow the PIP to be moveable, and screen video to be linked to logfile data of keystrokes and mouseclicks as well as annotation files made by project staff based on the Event Protocol. This may be especially useful for the less graphically-intensive SLEs.) It is also possible, when not mixing in user-participant video to record computationally intensive gameworld events under WindowsXP with the *FRAPS* program (<http://www.fraps.com/>).

The uncompressed AVI files can be edited and relevant shorter episodes selected from a session to be compressed with the appropriate (licensed) codecs into QuickTime or other formats for analysis and inclusion in the project database, where they will be available for further annotation, categorization, and application of qualitative analysis software tools such as those in *ATLAS.ti*. The interview sessions will also be recorded with the videocamera to DV tape cassettes and a similar procedure used for archiving and preparing them for analysis. This and other editing and conversion/compression work will require a semi-professional video editing software suite and format converter such as Adobe *Premiere* or Apple *FinalCutPro*. At least one project research assistant with expertise in digital video technology will be hired to oversee this work.

The video archive will contain a percentage of recordings without user-participant images and voice so that it can be made available to other researchers and developers of SLEs, consistent with protection of the rights of human subjects as agreed with the institutional IRB. Key episodes from both software-use sessions and interviews will be transcribed and included in the database as linked textfiles.

Broader Impacts

Integrating Research and Education

Project graduate research assistants will be trained in Semantic Discourse Analysis, Multimedia Semiotic Analysis, multimedia transcription and analysis techniques, and other advanced research methods both on the project and in two doctoral seminar courses (ED 805, ED 737) at the University of Michigan. These courses, continuing the

development of two new seminars which have already been taught for the first time, will also provide training in digital video research and analysis techniques for other doctoral students in the Learning Technologies and Science and Mathematics Education programs at the University of Michigan, including students already participating in several other NSF-funded projects (Herbst, ThEMaT; Krajcik, Moje, Fishman, et al., HiCE/CCMS; Palincsar & Magnusson, GISML; etc.) that work with textual, visual, video and multimedia data. It is expected that 10-15 research students per year will participate. We will continue our efforts to include increasing numbers of students from under-represented groups among our research students and those participating in the media analysis seminars. We will also make use of the expertise of our new colleague, Professor Kevin Miller (formerly Beckman Institute, UIUC), supported by NSF for current work using digital video to study classroom processes and their representation. This concentration of research efforts will create rich resources for students to learn to use digital media analysis methods in science and mathematics education research.

Data Sharing, Collaborations, & Dissemination

Session and episode video and interview transcripts will be made available to qualified researchers (subject to restrictions to protect the rights of user-participants). The records of user interactions with SLEs may be of considerable interest to their designers for improving usability features. Records of both SLE and gameworld use will also provide data for other researchers interested in the study of basic sense-making processes in rich multimedia and interactive-immersive virtual environments, including the growing number investigating computer gameworlds as platforms for STEM learning and for multimedia literacy. If the project is funded, collaborations with these researchers will be invited (e.g. Sasha Barab at Indiana, Yasmin Kafai at UCLA, Jim Gee and Kurt Squire at Wisconsin, Chris Dede at Harvard, Eric Klopfer at MIT). In addition research collaborations will be promoted with the games and learning research group at NESTA Futurelab (Bristol, UK; director, Martin Owen) and with Sharon Ainsworth's multimedia representations and learning research group at the University of Nottingham (UK). Initial contacts have already been made with all these research projects.

Results and findings from each stage of the project will be submitted as conference papers, as appropriate, for NARST, AERA, ISLS (International Society for the Learning Sciences), and DiGRA (Digital Games Research Association) and as manuscripts for publication (e.g. to *JRST*, *Science Education*, *JLS*, *GameStudies*). Project graduate research assistants will be encouraged to write or co-author and present or co-present papers. Preliminary research results will also be presented in talks at other universities where potential collaborative relationships can be built. Presentation and participation at DiGRA will require foreign travel to the Netherlands or Denmark in 2007 and 2008. Access to information about the project will be facilitated by a multimedia website.

Project Evaluation

The ultimate value of the project's outcomes will be evaluated by indices of the extent to which its work is cited in the science education, learning sciences, and learning technologies research literature and used in the development of future SLEs by others. The quality of the work will be evaluated by acceptance in peer reviewed journals and conference proceedings of papers produced. The internal validity of the project will be evaluated by the views of the expert advisory panel regarding the extent to which its data and analyses permit research-based judgments regarding Q3 primarily, and Q1 and Q2 in addition.

Wider Social Impact

This project aims to produce research-based guidelines for the development of next-generation, computer-based learning tools for the study of basic science. It will also potentially contribute knowledge which will be useful for assisting the development of multimedia literacy skills needed in science education and also increasingly in daily life. It will begin to assess which features of successful commercial computer games can be adapted to create better learning tools for science education, and it is also designed to contribute to basic knowledge about how people make sense of complex, interactive, multimedia environments.

I3W Project Schedule

Project Year/ Term	Major project activities
I / Fall (Sept – Dec)	Recruit 2 project GRA assistants Begin training GRAs to use Features Inventory Identify initial 3-6 digital CCGs and 3-6 SLEs Set up and pilot digital video recording system Test and refine Event Protocol Create initial project database Create project website
I / Winter (Jan – Apr)	Recruit 6-8 undergraduate user-participants Record initial user sessions and interviews Begin video and multimedia analysis seminar Identify relevant episodes, transcribe, add to database Begin analysis of key episodes
I / Spring-Summer (May – Aug)	Transcribe and analyze all key episodes Identify patterns of co-occurrence in atlas.ti Convene first expert panel meeting Frame hypotheses and plan further data collection & analysis Write first-year project Report
II / Fall	Record user sessions and interviews for targeted comparisons Begin transcription and analysis of new data Expand project database and refine hypotheses
II / Winter	Complete user sessions and interviews for targeted comparisons Conduct second video and multimedia analysis seminar Complete transcription and analysis of selected episodes Present preliminary findings at conferences and talks
II / Spring-Summer	Test hypotheses and co-occurrence patterns in atlas.ti Collate and synthesize evidence on Q1 & Q2 Convene second expert panel meeting Write project Final Report

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