

# NASA eEducation Roadmap: Research Challenges in the Design of Persistent Immersive Synthetic Environments for Education & Training

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Prepared for NASA eEducation

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## Introduction

Massive multiplayer online gaming and persistent synthetic environments, initially popularized in the entertainment world, are now finding growing interest in education and training environments. There is increasing recognition that these synthetic environments and games can serve as powerful “hands-on” tools for teaching a range of complex subjects. Virtual worlds with scientifically accurate simulations could permit learners to tinker with chemical reactions in living cells, practice operating and repairing expensive equipment, and experience microgravity, making it easier to grasp complex concepts and transfer this understanding quickly to practical problems. Massively multi-player online games, or MMOGs, help players develop and exercise a skill set closely matching the thinking, planning, learning, and technical skills increasingly in demand by employers. These skills include strategic thinking, interpretative analysis, problem solving, plan formulation and execution, team-building and cooperation, and adaptation to rapid change. In addition, today’s students who have grown up with digital technology and video games are especially poised to take advantage of the MMOG communications and community building tools to collaborate on complex projects and ask for help from teachers and experts from around the world.

NASA’s eEducation program has committed to develop a commercial quality MMOG based on NASA’s vision and mission. The MMOG will be based on game technology with accurate physics rendering. NASA’s goal is to provide a *scyberspace* where students and teachers, engineers and scientists, researchers and designers can immerse themselves in accurate representations of NASA facilities, missions, careers and data (Laughlin, 2007).

NASA is not alone in its interest in MMOGs and persistent synthetic worlds as learning environments. Educational MMOGs have been discussed at several meetings and conferences including the Serious Games Summit 2005 and 2006, the Federation of American Scientists’ Summit on Educational Games 2005, and the National Academies Game-based Learning Workshop, 2005. The Department of Defense, the National Science Foundation and the National Institutes of Health have funded development of educational games.

To date, however, there has been no coherent strategy employed to guide the development and assessment of an educational MMOG. There is a general consensus that educational games are not the same as today’s commercial video games. Educational games represent a new type of product — where the knowledge of pedagogy is integrated with the features of games that are so motivating, engaging, and rewarding to users (FAS, 2006). This requires expertise

beyond the specialists that design commercial entertainment games. There is a pressing need for a research road map to guide developmental efforts.

To address this need, NASA eEducation and the Federation of American Scientists collaborated to develop this road map to raise awareness of key research challenges, and to encourage dialogue and partnerships in carrying out activities needed to support the development and design of educational MMOGs and massively multi-user virtual environments (MUVES).

The research strategy identified in this road map will guide NASA's eEducation effort to build upon a collaborative framework. By developing an MMOG with specific research questions identified in advance, research consideration can be factored into development. Following the research plan also provides strong opportunities to establish a collaborative research base between government agencies, private foundations, universities, educational institutions and commercial entities.

## Research Plan Overview

This document presents a research and development plan, or "road map," for the development and application of MMOGs and MUVES for learning in education and training settings. The road map builds on previous Federation of American Scientists work on educational games. *R&D Challenges in the Design of Games for Learning* (FAS, 2006) was developed with inputs gathered during the 2005 Summit on Educational Games that explored ways that the features of games could be applied to address the increasing demand for high quality education and training, and ways to address barriers to private sector investment in learning games-related research, product development, and new product and service introduction. The Summit's 100 participants included business executives from the gaming industry and the education software industry, researchers and academic experts on technology and pedagogy, teachers, game developers, experts on competitiveness policy, and government policy makers. The research priorities described here are also derived as a subset of the research priorities identified in the 2003 Learning Science and Technology (LS&T) R&D Roadmap produced by the Federation of American Scientists' Learning Federation Project. The LS&T Roadmap describes a vision for next-generation learning systems, and outlines a national research plan to radically improve approaches to teaching and learning through information technology. The LS&T R&D Roadmap was produced over a two-year period with input and advice from over seventy researchers from industry, academia, and government through their participation in focused workshops, interviews, and preparation of technical plans. Comprised of a series of five component road maps, the Road map provides an assessment of R&D needs, identifies key research

questions and outlines a chronology of R&D activities designed to spur innovation in technologies for education and training.

## Research Focus Areas and Priorities

The goal of the research identified in this road map is to create a new breed of learning environments by intelligently applying the lessons, techniques, and technologies of computer and video games. Students often complain that they do not see real-world applications for what they learn in math and science classes. Would these students draw more fully on such knowledge if it were the key to solving puzzles or overcoming obstacles in a game environment? Because many important aspects of the physical world cannot be directly experienced, synthetic environments could help by providing learning spaces that represent or mimic reality and permit expertise to be built over time. Features of MMOGs and virtual communities could be used to provide learning environments that adjust to the skills of their players, allowing the same environment to meet the needs of a novice as well as a more advanced student. Social networking features of online environments, such as those exemplified in *Second Life*<sup>TM</sup>, could provide capabilities that enable people to find each other, form communities, share information, and collaborate on a variety of endeavors. Understanding how best to exploit the features of MMOGs and synthetic environments for education and training will require that we understand which features of these systems are important for learning and why.

The research priorities in this road map focus on learning rather than the underlying technology. Five research focus areas or topics are described. Associated with each research area will be an array of software tools and a set of priorities that need to be accomplished. In order to track progress, milestones for each task are projected for the next 3 years, 5 years, and 10 years.

The research focus areas are:

**1) Instructional Design.** Research challenges in instructional design focus on understanding effective learning strategies for each subject and each learner and how to use this information to design the learning experience. Research priorities include:

- Understanding the features of challenges that are crucial for motivation
- Understanding how stories/scenarios contribute to motivation and learning
- Understanding the impact of immersion and engagement on learner motivation
- Linking gaming features to goal orientation in persistent environments

- Developing a framework to enable generalization and integration of research

**2) Stimulating Questions and Answering Questions.** Research topics address how to take advantage of the benefits offered by emerging technologies to facilitate inquiry and get questions answered. Four key research priorities are identified for increasing the frequency and quality of questions, as well as methods for delivering answers to learner questions.

- Methods and tools to stimulate learner questions and generate questions that stimulate learning
- Interfaces that make it easy for learners to ask questions and to provide guidance on what sorts of questions can be (or should be) asked
- Tools for interpreting learner answers
- Tools to advance the discussion and to summon teachers and experts as needed

**3) Feedback and Assessment.** Feedback and guidance are essential components of a learning environment. They point out performance errors, correct them, and allow the learner to proceed to mastery. Assessment also permits evaluation of the learning environment itself. Research task priorities are:

- Learner models capable of assessing important knowledge and skills and measurement methods to improve learner feedback
- Frameworks for internal evaluation of a game's content and functioning and external evaluation focusing on learner interactions and resulting learning gains and for assessing how the game was used in the teaching environment

**4) Building Simulations and Synthetic Environments.** Research questions address how to make it easier for communities to work collaboratively to build complex virtual environments that reflect current understanding of physics, chemistry, biology, mathematics, and other disciplines that permit exploration-based pedagogy. Research priorities are:

- Interoperability to permit combination and reuse of software objects and simulations
- Certification, reuse, updating, and maintenance of simulations and objects

**5) Integration tools for building and maintaining learning environments.** This research topic addresses the need to examine existing and emerging

interchange protocols, formats and services that relate to the entire process of content development through to deployment. Interfaces to services such as authentication, learner profiles, and assessment, also need to be identified and rationalized. Research priorities are:

- Course building tools for designing scenarios, creating assignments, designing response to information gathered from student observer tools, and programming avatar behaviors
- Shareable Content Objects that can hide the underlying technology and use terms and visualizations familiar to instructional designers
- Tools and services to assist developers in the application of metadata.
- Tools to establish an open process for worldwide collaboration on building and maintaining learning environments

The following sections discuss each research topic area and identify research priorities and milestones for each.



## Research Focus Area: Instructional Design

The research agenda includes the development of libraries of techniques and sound, validated principles for instructional designs that will enhance learning. Instructional design provides a means of structuring the delivery of content for learning in a meaningful and effective way. Effective instructional design incorporates current understandings on how people learn, how experts organize information and the skills of effective learners. The challenges for instructional design in games for learning concern both the presentation of educational materials and the learner's experience of the game play.

Online, persistent, computer-based and console games present specific opportunities and challenges for conveying learning content. Games generally consist of challenges, competition, story, characters and score-keeping. While the impact and application of several of these facets are well understood in the context of entertainment (e.g. sports, literature and the performing arts) focused research is needed to apply their benefits effectively to designing learning games. To begin, research is needed to identify which, if any, of these elements or combination of elements are essential for learning to occur, which lead to better outcomes or map to specific learning tasks and goals. For example, score-keeping may positively impact one type of game or learning style but hamper another. Further research should be devoted to dissecting, understanding and applying what is crucial about each feature for motivation and learning, and how they may be applied to specific subject areas and learner characteristics. Finally, research is needed to determine how these features accommodate different learning styles.

MMOGs share some similarities to stand-alone games, but also present alternative capabilities and opportunities for learning. Work must be undertaken to investigate how to leverage the non-sequential, open-ended nature of these immersive online innovation environments that offer user-generated, user-modified content and experiences.

### Instructional Design Research Priorities

Understanding the features of challenges that are crucial for motivation and learning

Game design often incorporates progressively more difficult challenges to keep players balanced on the edge of frustration with the level of difficulty and satisfaction from achieving a goal. Learning content in games must be structured to provide both satisfaction and frustration. Challenges must also be authentic to the game and woven into the narrative in order to meet the player's expectations. The learner's needs, background and abilities must also be considered in the design and presentation of the learning materials. A variety of techniques, from

providing worked examples to including characters to guide, offer help, and provide feedback need to be researched and rated for effectiveness.

Discovery-based learning has been shown to be most effective when students receive guidance in the form of coaching and hints. Absent proper guidance and feedback, discovery-based learning can be ineffective and learners may learn incorrect concepts (Hammer, 1997). It has been shown that learners often do a poor job of dealing with large amounts of anomalous data that appear in a simulation (Chinn & Brewer, 1993; Chambers et al., 1994.) Once learners have a hypothesis, they may be likely to engage in a phenomenon called confirmation bias in which they look to support rather than refute their working hypothesis. The dangers here are that learners may navigate the learning environment seeing only what they want to see and, therefore, miss clues that would guide them to a more fitting or appropriate hypothesis (Bonk, 2005).

Educational MMOGs and MUVE may need to incorporate appropriate scaffolds for learners as a means to guide them through the learning process. Bransford, Brown & Cocking (1999) discuss the use of technology to scaffold experience. They use the analogy of “training wheels” as a means to explain how computerized tools can be used to support learning that students would otherwise be unable to accomplish. Scaffolding comes in the form of modeling, giving students cues and prompts, hints and partial solutions. These features can automatically adjust the level of challenge to maintain the learner’s level of engagement and motivation. De Jong and van Joolingen (1998) outline three of the most promising strategies for building scaffolding: ready access to domain-specific information, game-like assignments driven by questions and exercises, and a learning environment with model progression. .

The player’s interests and cognitive abilities are an important consideration in the kinds of scaffolding and feedback offered, but also in the mapping of content to objectives and expectations. Games and other e-learning environments have great potential to offer scaffolding for learner needs and feedback on performance. Research is needed to identify the features of challenges that increase motivation and learning and techniques that optimize the introduction, format, timing and fading of scaffolding, in the learning environment. For example, should game play be stopped in order to provide cues and hints; how much coaching is optimal?

Research Milestones for understanding the features of challenges that are crucial for motivation and learning

*3 year milestone:* empirical research demonstrating the features of challenges that increase motivation and learning.

*5 year milestone:* guidelines for structuring challenges in terms of difficulty (and other features) to optimize learning; demonstrations of techniques that optimize the introduction, format, timing and fading of scaffolding in the learning environment.

*10 year milestone:* empirical results linking challenges to learner characteristics such as prior knowledge, prior skill, prior experience, misconceptions, and interests; automated tools that can adjust scaffolding strategies automatically as a function of learner characteristics and on-going performance.

### Understanding how stories/scenarios contribute to motivation and learning

In many video games, the story/scenario is the bridge linking missions, and providing the necessary goals and motivation to progress to the next segment of game play. Narrative can be used to engage the learner in challenging tasks, stimulate curiosity, provide pacing and support multiple aspects such as reflection, comprehension, exemplification, etc. (Conle, 2003). Narratives that drive computer or console games are generally linear or use a relatively simple branching structure and are rule-based (Juul, 2006), while a multitude of elements, especially those created by players themselves contribute to the narrative experience in persistent environments (Morie, 2001). MUVES generally have user-driven narratives and the success of *Second Life*<sup>TM</sup> demonstrates that many users desire the freedom to create their own story. For learning environments, this may be exemplified by teachers, instructors, and experts building their own domain-specific virtual settings and scripting their own stories or metaphors to guide learners.

Research Milestones for understanding how stories/scenarios contribute to motivation and learning

*3 year milestone:* empirical results demonstrating the features of story/scenario that are crucial for motivation; identification of techniques that help the learner see the learning goal as important, interesting and useful.

*5 year milestone:* demonstrations of the use of stories/scenarios that increase learners' receptiveness to learning.

*10 year milestone:* mechanisms to assess the appropriateness of a story for learning; guidelines for developing compelling, effective stories for learning.

Understanding the impact of immersion and engagement on learner motivation

The setting of video games can also be exploited for learning opportunities. Settings can range from painstakingly reconstructed photo-realistic settings to abstract or minimalist environments, as long as they meet players' expectations of internal logic and consistency. Immersion is defined as the experience of feeling a part of the synthetic experience (Stanney, 2002). As with narrative, immersion and engagement contribute substantially to the player's experience, enjoyment and time spent on task. Different levels of fidelity are necessary to meet different learning tasks.

Games allow players to assume the role of an avatar and often make use of simulated actors or avatars who provide real-time coaching and advice to address learners' misconceptions (Cassell, 1999). This holds true for both games and persistent environments. Having virtual representations of players in online worlds and interacting with other avatars is a key motivator in online environments. New developments in technology are enabling avatars to become more personalized, dynamic, interactive and able to be encoded with the user's interests.

Research is needed to determine player expectations necessary to provide an immersive experience and the corresponding level of fidelity necessary to engage players, stimulate learning and avoid negative training. Research is needed to explore learning through player interaction (both in scripted games and persistent environments), through creating or building game content such as buildings, textures, animations, and through in-world experiences to determine what is most

effective for learning. Research must be undertaken to identify the variables that affect players' experience, such as the level of fidelity needed for the player to experience immersion. Individual differences may affect the level or the experience of immersion, (Kaber, Draper and Usher, 2002) and research is needed to develop psychometrically sound techniques for assessing immersion and engagement. From this research, guidelines can be drawn up for the community and tools can be designed to assess the player's level of immersion in game environments.

#### Research Milestones for Understanding the Impact of Immersion and Engagement on Learner Motivation

*3 year milestone:* research studies to define immersion and engagement as viable psychological variables; studies demonstrate the impact of immersion and engagement on learner motivation.

*5 year milestone:* demonstration of psychometrically sound techniques for assessing immersion and engagement; identification of game features that contribute to immersion and engagement.

*10 year milestone:* guidelines for use of game features to increase immersion and engagement; accepted approaches/automated tools for assessing the degree of immersion and engagement game environments.

#### Linking gaming features to goal orientation in persistent environments

Games provide a variety of highly-motivating features to keep different types of players interested and to encourage their audience to continue playing even after repeated failures to achieve a goal or objective. Presenting authentic goals that provide compelling reasons to undertake them is important for learning and a critical feature of good game design. Some successful games also provide environments that increase engagement by allowing players to perform independent tasks. Mechanisms to track progress also play an important part in motivation and learner assessment. Narratives are a crucial component in goal orientation and help to encourage players to achieve the game's goals and objectives. As stated earlier, computer or console-based game narratives are generally linear or use a relatively simple branching structure. Dynamic interactive narratives in which the player's decisions directly affect the outcome of the game are being explored (Baylock, 2003, Magerko, 2004, Bradford, 2006). MMOGs or other persistent worlds rely on cues in the environment and interaction among players to create story, meet level objectives and achieve goals.

MMOGs --especially persistent worlds-- are more open-ended than scripted video games and through the encouraged social interaction these platforms offer, they permit learners to benefit from the collaborative learning and collective experience of other players. Research is needed to explore and to determine how to link goal orientation with learning objectives and the role story plays in games and virtual worlds to enable participants to achieve their learning objectives effectively . Specific research is needed to study the less-structured character of persistent environments, especially to direct character actions and maintain engagement.

#### Research Milestones for Linking Gaming Features to Goal Orientation in Persistent Worlds

*3 year milestone:* research studies to increase the community's understanding of how the design of persistent worlds affects goal setting and goal acceptance.

*5 year milestone:* empirical studies demonstrating approaches to enhance the setting of learning goals; identification of mechanisms to enhance learners' ability to track and monitor goal accomplishment.

*10 year milestone:* guidelines for use by the community.

#### A framework to enable generalization and integration of research

Based on a systematic program of research and empirical results that link scripted and online multi-player games to task features and learner characteristics, guidelines of best practices for effective instructional design can be codified. For each of the specific research and development goals highlighted above, the long-term milestone is to develop guidelines for the diverse community of practitioners. One of the biggest challenges in reaching this goal, and a problem plaguing much of the research in this area, is that it is conducted on specific content, with specific learners, under specific conditions. Unfortunately, the generalizability of results is often not investigated or known. In fact, perhaps the biggest problem with past research in this area is a lack of coherence—that is, there is no integrative framework in which research results can be interpreted or applied. The outcome is a plethora of individual studies with associated results, but no mechanism to paint a picture of how these fit together, how widely they can be applied, or how and why they are limited. For example, a line of research may discover that presenting worked examples aids students in learning mathematical concepts. By themselves, these results do not indicate how well the same strategy might work for explaining concepts involving electricity or principles of accounting.

Essentially, individual results are left to stand on their own and the instructional designer is forced to sift through a large corpus of results with little explicit guidance on why or how they might apply to the situation at hand.

To remedy this, a program of research is needed that aims to elucidate and investigate in a systematic way the host of variables that will have an impact on instructional effectiveness for a particular application. In general, such an approach would be concerned with what is being taught, who the learners are, which phase of instruction is of interest, how best to teach targeted material, the context in which learning will occur, and any practical considerations that limit what can be done. One way to organize a systematic program of this sort is to construct an overriding model or framework that lays out all of the pertinent variables and the manner in which they are related. Using such a model would provide researchers a common framework in which to conceptualize their studies and make it easier to see how individual studies (i.e., the specific variables and context being tested) fit into the larger picture. In addition, a common framework will allow research results to be more effectively integrated across factors, and gaps in understanding to be identified.

Research Milestones for a framework to enable generalization and integration of research

*3 year milestone:* corpus of research identified; community of practitioners identified and linked; variables identified; studies integrated.

*5 year milestone:* vocabulary issues identified; tools for translating among STEM disciplines developed to promote coherence; initial framework agreed upon by the community.

*10 year milestone:* guidelines for the framework accepted by the community; impact analysis shows improved exchange of research results.

**Research Focus Area: Stimulating Learners to Ask Questions and Providing Answers to Questions**

The research agenda includes methods for increasing the frequency and quality of questions, as well as methods for delivering answers to learner questions. Research has shown that learning often improves when students are stimulated to ask questions and when there are facilities for receiving relevant, correct, and informative answers. (Beck, McKeown, Hamilton, & Kucan, 1997; Dillon, 1988;

Graesser, Langston, & Baggett, 1993; King, 1994; Miyake & Norman, 1979; Pressley & Forest-Pressley, 1985; Schank, 1999).

Question generation is understood to play a central role in learning because it both reflects and promotes active learning and construction of knowledge (Bransford, Goldman, & Vye, 1991; Brown, 1988; Graesser & Wisher, 2002; Otero & Graesser, 2001; Papert, 1980; Scardamalia & Bereiter, 1985). Yet, it is well documented that student questions are rare in most learning environments (Dillon, 1988; Graesser & Person, 1994), so there is a need to identify learning situations that stimulate questions, such as challenges, contradictions, and obstacles to important goals (Graesser & Olde, in press). Learning improves when learners are taught how to ask good questions, either through direct instructions on question asking (King, 1989, 1994; Rosenshine, Meister, & Chapman, 1996) or by a person or computer that models good question asking skills (Craig, Driscoll, & Gholson, 2002; Palincsar & Brown, 1984).

A key challenge is to find ways to facilitate inquiry by taking advantage of the benefits offered by emerging technologies. That is, how can we use what we know about question generation and question answering to design learning environments that guide learners to construct knowledge actively?

Research and tool development for question asking and answering is being conducted by many groups. The Text REtrieval Conference (TREC) is an initiative co-sponsored by the National Institute of Standards and Technology (NIST) and the Defense Advanced Research Projects Agency (DARPA) whose purpose is to support research within the information retrieval community by providing the infrastructure necessary for large-scale evaluation of text retrieval methodologies. Many commercial enterprises are developing and using sophisticated automated Q&A systems such as help desks, customer support centers, and web search based systems such as Ask.com.

NASA can play an important role in Q&A for eEducation systems by encouraging use of Q&A tools in its eEducation applications and designing research objectives for its eEducation projects that will contribute to a broader understanding of how to increase the frequency and improve the quality of questions and improve methods for delivering answers to learner questions. Evaluation methodologies that enable summative and meta-analysis across NASA funded projects would be extremely beneficial to the broader e-learning research community.



## Question Asking and Answering Research Priorities

Tools to stimulate learner questions and generate questions that stimulate learning

Activities in this area contribute to a better understanding of the characteristics of learning environments that trigger particular categories of questions, with a focus on environments that stimulate genuine, information-seeking questions, rather than questions merely to attract attention, monitor conversation flow, or serve social functions.

### Research Milestones for tools to stimulate learner questions and generate questions that stimulate learning

*3 year milestone:* decision aids for identifying the critical components of learning environments that stimulate question asking.

*5 year milestone:* published models that predict how varying features in a learning environment change quantity and types of questions.

*10 year milestone:* repositories of sample questions for additional new classes of learning environments.

Interfaces that make it easy for students to ask questions and to provide guidance on what sorts of questions can be (or should be) asked

Activities in this area focus on better understanding appropriate multimedia designs to use for asking and answering questions. For example, when is it best to deliver information in printed text versus speech, in language versus highlighted pictures, in static illustrations versus animated simulations, or to summon a human instructor or expert? In most MMOGs and MUVES information is provided on “note cards” or chatted into the applications. For example, virtual museum applications use “tour bot” agents that greet visitors and take them on a pre-determined track with descriptions of the exhibits. The stopping points and text for the descriptions sit inside the “bots” as note cards. (Kemp, 2006). Ideally, information and answers would be tailored to address each learner’s specific questions and tailored to meet the learner’s knowledge level.

Research Milestones for interfaces that make it easy for students to ask questions and to provide guidance on what sorts of questions can be (or should be) asked

*3 year milestone:* environments that transmit learner questions to the author or publisher along with student reports of adequacy of answer; markup language for supporting question answering from large text collections; usability studies of interface features examine question-asking frequency with and without specific features.

*5 year milestone:* large text collections manually annotated with Q&A markup language; formative evaluations of interface features that examine average question quality and changes in question quality (learning to ask good questions) with and without the feature.

*10 year milestone:* summative evaluation of interface features that examine domain learning gains with and without the interface feature; automated markup of large text collections in support of question answering.

Interfaces that make it easy for students to ask questions and to provide guidance on what sorts of questions can be (or should be) asked

Learners find it easiest to express themselves when they can combine speech, gesture, and facial expressions. Information from all of these input modes must be interpreted, deeply comprehended, and evaluated pedagogically.

Research Milestones for interfaces that make it easy for students to ask questions and to provide guidance on what sorts of questions can be (or should be) asked

*3 year milestone:* examples of systems that support complex answers compiled, merged, and generated from multiple sources, with confidence level.

*5 year milestone:* examples of dynamically constructed answer justification.

*10 year milestone:* learning environments tailored automatically to maximize the landscape of important questions.

Tools to advance the discussion and to summon teachers and experts as needed

Students' interest or engagement in a task is clearly important, but it does not guarantee that students will acquire the kinds of knowledge that will support new learning. Learners need to understand an overall picture that will lead to the development of integrated knowledge structures and information about conditions of applicability (Greeno, 1991). Effective question-answering tools need to respond to what the student says and also advance the conversation to meet pedagogical goals. These tools should be able to recognize when the automated approach reaches its limit and summon teachers or other experts, as needed. These teachers or experts should be able to understand the context of the question and know relevant details about the student so that their responses can be thoughtful, prompt, and relevant.

Research Milestones for tools to advance the discussion and to summon teachers and experts as needed

*3 year milestone:* evaluation experiments to assess effectiveness of approaches.

*5 year milestone:* demonstration systems capable of asking the learner major questions or presenting problems that will require major attention and conversation; systems that summon teachers or experts, as needed.

*10 year milestone:* systems that direct the learner to simulation and visual media.

### Research Focus Area: Designing Simulations and Synthetic Environments for Learning

Some authors are dubbing the current generation of students the "We Generation" for their deep involvement with social networking (Olsen, 2007). Connection to family and friends through technology is not a recent innovation signaling the pace of change starting in the late twentieth century: it is the only reality they have ever known. The rising popularity of MMOGs and MUVES is one expression of this connectedness. It can also be seen in the explosive growth of social networking tools like MySpace and YouTube. At the same time, growing numbers of people are using technology to keep in touch with one

another (Annenberg, 2007), the ability of technology tools to communicate with each other has reached a new level of maturity (Gates, 2007).

One reason for NASA eEducation to support an educational game approach based on MMOG technology rather than stand-alone games is because of the social and collaborative strengths of the former. Simply having many users inside the same synthetic environment is, however, only one portion of the goal. It is important to have a synthetic environment with as many means of access, connectivity and information exchange as possible. Already *Second Life*<sup>TM</sup> demonstrates these features by allowing video streaming in the environment, synchronous and asynchronous chat tools among the tools available to users. Further development should build on that model to develop a synthetic environment where access by computer and cell phones and other handheld devices are valid means of reaching the synthetic world. Podcasts, vodcasts, email, text messaging, voice chat, video streaming and more should all be able to go both into and out of a synthetic environment.

Castronova (2005) foresees an evolution of synthetic environments to the point where the environments themselves interface and avatars are able to cross from one realm to another and users' digital personae remain constant regardless of the environment. Such a vision may be difficult to achieve, but embodies the spirit of synthetic environments and extends it to the idea of an immersive network where users plunge into the Web itself and all of the environments and media interfaces are simply nodes and channels linking and crisscrossing in a single immersive 3D virtual space.

## Simulation and Synthetic Environments Research Priorities

### Interoperability

Building complex virtual environments that permit exploration-based pedagogy requires an unprecedented investment for building an effective community from the numerous groups of people that must contribute to developing these tools. Some synthetic environments already permit the players themselves to participate in modification and improvement of the games and virtual worlds. In *Second Life*<sup>TM</sup> the players create most of the content of the world, including their own avatars; players are provided with a 3D modeling tool that allow them to build virtual buildings, landscape, vehicles, furniture, and machines to use, trade, or sell. Players can also use modeling tools outside the virtual world to create items and upload them. *The Sims* spurred a network of player websites that showcased custom *Sim* objects and characters (Bork, 2005). According to Herz & Macedonia (2002) ninety percent of *The Sims* game is produced by the player population.

*World of Warcraft*, one of the most popular MMOGs, is an example of a central content creation model.

Virtual worlds suitable for science and engineering education will need to be scientifically accurate. Building such environments will require effective combination and reuse of software objects and will require agreement on the coordinate systems and methods for representing complex geometric objects, the system of units employed, and the exact terminology used to describe objects (or ontology). Simulations show motion and interaction and thus require a precise taxonomy of verbs—that is, rates of change and flows of charge, chemicals, and bulk materials. They must also show changes in shape and even basic topology of objects.

Research Milestones for interoperability to permit combination and reuse of software objects and simulations

*3 year milestone:* community-wide efforts to agree on interchange standards and tools.

*5 year milestone:* demonstration of software architecture and tools that permits combination of software objects by multiple authors.

*10 year milestone:* development of a 3D modeling environment that can be used for modeling dynamic interactions and organic shapes.

Reuse, updating, and maintenance of simulations and objects

A lightweight management structure can establish and enforce a set of simple rules, oversee final decisions about which objects offered meet the required standards, and maintain an index of components built to the agreed rules. Open source communities provide one such model for building a community of developers capable of providing the advanced simulation tools needed for science and engineering education. Many MMOGs benefit from highly committed gamers who contribute to or invest in the community by finding and eliminating bugs or flaws. Acknowledgement appears to be an important motivator for these individuals. In effect, they take some ownership over the learning process. The respect and recognition that they receive from the community for their work enhances that environment and fuels additional participation and pride. (Rickard & Oblinger, 2004).

Research Milestones for reuse, updating, and maintenance of simulations and objects

*3 year milestone:* established procedures for peer review and validation of results against experiment.

*5 year milestone:* procedures for bug reports and reliable version control.

*10 year milestone:* methods for tracking of the provenience of data and methods and identification of authors; methods and tools to ensure that appropriate credit is given to authors.

### Research Focus Area: Feedback and Assessment

Feedback and guidance are essential components of a learning environment. They point out performance errors, correct them, and allow the learner to proceed to mastery. As the learner interacts with the information and practice resources, the system should overtly or unobtrusively gather data on learner mastery, motivation, and metacognition (reflecting and directing one's own thinking). This information should be used to dynamically adapt content or generate feedback and guidance to the learner or trigger intervention by a human expert or intelligent agent, or to inform the decisions of a human teacher.

In addition to measuring the players' learning outcomes, assessment activities should include assessment of the learning environments themselves to inform and guide research approaches, assess progress, and understand how well the learning systems promote learning. This assessment should aim at the continuing improvement of MMOGs/MUVEs. As outlined in the priorities for Instructional Design, a common assessment framework is needed which would make it easier researchers to understand how individual studies (i.e., the specific variables and context being tested) fit into the larger picture and allow research results to be more effectively integrated across factors, and gaps in understanding to be identified.

#### Feedback and Assessment Research Priorities

##### Learner Models and Measurement Methods

The first step in the assessment development process is to specify the constructs (skills, knowledge, and abilities) to be measured. This requires analysis of the

content/job/performance domain into its constituent knowledge and skill components. Such analysis results in lists, clusters, and hierarchies of skill components (or learning/assessment objectives) at various levels of granularity. The more fine-grained the analysis, the more test items, or responses within larger assessment tasks, can be targeted at particular subskills, and the more specific the diagnosis of knowledge gaps and the greater the validity, efficiency, and effectiveness of the resulting assessment and learning. (Clark, 2002; Sugrue, 2002; Cannon-Bowers, 1995). Students taking Cognitive Tutor Algebra I have been shown to perform 85% better on average on assessments of complex mathematical problem solving and thinking. The tutor uses a fine-grained cognitive model to assess student progress on mastering skills and then diagnostically assigns problems based on the individual student's needs. (Koedinger, 2000).

One of the main problems with current state-of-the-art knowledge is that there are any number of models, taxonomies and techniques in use for defining tasks and knowledge. The existence and use of so many models makes it difficult to agree on general components of performance across domains and to perform task/content analysis, assessment design, or score interpretation across domains or across learning systems. (Baker, 2002).

Another key challenge is developing effective methods to measure and assess what can be learned from these new types of learning environments. MMOGs and MUVes may be especially effective in developing higher-order skills — such as strategic thinking, interpretative analysis, problem solving, and decision-making. For example, in typical video games, players are making decisions continually, in contrast to low levels of decision-making in traditional learning. Educational games and simulations may also be effective in developing complex aspects of expertise, not simply short-term memory of facts. These higher-order knowledge and skills are typically not revealed by tests of facts, or standards of learning-types of examinations. If assessments are not measuring the right skills and knowledge — the higher order skills that games may be able to develop — then the use of educational games and simulations may be viewed as having poor efficacy. NASA needs to ensure that the knowledge, skills, and abilities it deems important are being measured.

Prototype software, demonstration projects, and studies that compare models will help lead to guidelines and decision-aids for choosing different measurements and appropriate level of granularity based on context, budget, and purpose.

### Research Milestones for learner models and measurement methods

*3 year milestone:* higher order skills NASA deems a priority defined and integrated into assessments; prototypes of models embedded in some MMOGs/MUVEs; tools to easily insert monitoring functionality in variety of MMOGs/MUVEs.

*5 year milestone:* results of empirical studies that compare methods for delivering feedback; studies comparing efficiency, utility, and validity of different learner models in different contexts.

*10 year milestone:* guidelines and decision-aids for choosing different measurements and appropriate level of granularity based on context, budget, and purpose.

### A Framework for Assessment of Learning Systems

In addition to measuring the player's learning outcomes, assessment activities should include assessment of the learning environments themselves to understand how well they promote learning. Bork (2005) suggest application of Siemer's (1995) evaluation methodology for intelligent gaming simulations to MMOGs. Siemer's methodology is based on Littman and Soloway's (1988) proposal for evaluating intelligent tutoring systems using analysis of three key parts of the program: (1) Knowledge level (does the program contain sufficient knowledge to meet learning objectives?); (2) Program process (how does the program work?); and (3) Tutorial domain (what should the program do?) Bork recommends both an internal and external evaluation of MMOGs, with the internal evaluation focused on evaluation of the game's architecture, what it does, and how the game reacts to play input.

External evaluation would study the game's usefulness to the learner in terms of both promoting learning and motivating the learner. It is important to note that evaluations could find considerably different outcomes — derived from the same technology-based intervention — due to differences in how the technology was implemented. Evaluations should also consider how instructional practices, teacher preparation, school environment, and other factors have affected outcomes. A common assessment framework is needed to allow generalization and integration of the assessment efforts.



Research Milestones for a framework to enable generalization and integration of research

*3 year milestone:* corpus of research identified; community of practitioners identified and linked; internal and external variables identified.

*5 year milestone:* vocabulary issues identified; tools for collecting and reporting assessment data developed to promote coherence; initial framework agreed upon by the community.

*10 year milestone:* widespread use of guidelines by the community; reporting of assessment by community in common constructs and framework; impact analysis shows improved exchange of research results.

### Research Focus Area: Integration Tools for Building and Maintaining Learning Environments

NASA creates and owns many simulations, videos, digital models, instructional materials that could be made available to support development of learning systems and environments. A focus of this research area is to develop processes, methodologies, frameworks, and tools to enable sharing of this content and use of it within synthetic environments and MMOGs. The Shareable Content Object Reference Model (SCORM) is one initiative that has been developing standards and specifications (<http://www.adlnet.gov/scorm/index.cfm>). Content development is the deliberate process of creating and organizing a variety of digital assets such as text, graphics, pictures, illustrations, and etc., into a form that can be electronically delivered to a learner. Visibility of the digital assets is important and should be a key feature – unless this content is visible, it can't be accessed, understood, and shared. A major component the research discussed here addresses research focused on determining how systems and users will make use of metadata after it exists. This will spur development of new research and use services and the development of tools that will produce useful results.

A key goal is to simplify the steps between content creation and deployment. To do this, it will be necessary to look at the entire development process from an architectural perspective to determine workflow and interchange requirements. Tools are needed to allow content to be developed and tested with few

intermediate steps and which hide the underlying complexity of the development work.

Existing and emerging interchange protocols, formats, and services need to be examined that relate to the entire process of content development through deployment. Interfaces to other services such as authentication, learner profiles, and assessment need to be identified and rationalized. Experiments that demonstrate the interoperation of different levels of development are needed.

### Integration Tools Priorities

Tools are required that hide the underlying technology completely and that use terms and visualizations familiar to instructional designers. More people who understand learning and instruction will be able to contribute to a growing body of shareable content objects if simple and easy to use tools (even by non-technical authors) are made. Development costs will reduce, and quality will increase as communities of practice develop. In order to be accessible to a wide audience, the hope is that the tool evolution will follow paths taken by word processing and presentation software. Until this happens, however, content development will remain out of the reach of the very people who are best suited to create engaging and effective learning content.

### Course Building Tools

How do content creators think and work? What capabilities would best enable them to create content and what would impede them? A new line of research is needed to look at content creation from a fresh non-technical perspective that is not bound to legacy authoring tool products and that reflects the community of practice of learning design. The results of this research would produce functional requirements for next generation tools, infrastructure implications (e.g., external enablers required/assumed), prototype tools and interfaces to test acceptance, and pilot applications to test effectiveness.

#### Research Milestones for course building tools

*3 year milestone:* different methods for creating instructional experiences identified based on theory and practice and effectiveness evaluated.

*5 year milestone:* tools that create rich instruction but hide the complexity of implementation demonstrated and tested.

*10 year milestone:* libraries of strategies for multiple domains built.

## Storage/Retrieval of Shareable Content Objects

This research area focuses on understanding how designers might search for and access content from disparate sources and should examine both the metadata, repository, and search requirements for rapid and rich content development.

### Research Milestones for storage/retrieval of shareable content objects

*3 year milestone:* evaluate current and emerging sequencing tools to determine if they meet designers needs; determine best strategies.

*5 year milestone:* expand sequencing and navigation capabilities.

*10 year milestone:* evaluate tools to automate the process.

## Tools and services to assist developers in the application of metadata

Standards for learning object metadata now exist, but few tools or practices have been developed. These tools need to be customized to meet the needs of various communities of practice. Research is also needed to determine the semantics of metadata in different domains and develop implementation guidelines for developers in those domains, and to examine the means to map semi-automatically across domains and determine the impact on content developers. A special area of required research would develop tools and/or agents that can perform intelligent searches of metadata during authoring, and eventually in real time, for “on the fly” content aggregation.

### Research Milestones for tools and services to assist developers in the application of metadata

*3 year milestone:* evaluate advanced, intelligent search strategies and engines; determine the semantics of metadata in different domains and develop implementation guidelines for developers in those domains.

*5 year milestone:* evaluate tools that aggregate learning activities/content based on context-based searching strategies for gathering content to meet specific criteria; evaluate tools to relate metadata from different domains that are instructionally sound.

*10 year milestone:* develop and test rules that intelligently guide search and retrieval based on metadata; evaluate on the fly aggregators: "teach me this topic now; build me this course now."

### Tools for collaborative building and maintenance of learning environments

NASA has a wealth on materials developed as part of its many education activities. Ideally, this instructional content should be developed as potentially reusable and interoperable objects, and those objects organized into contextually relevant groups for delivery to the learner. Work is needed to establish technology standards for content and to better understand the process of creating instruction through the aggregation of content objects.

#### Research Milestones for tools for collaborative building and maintenance of learning environments

*3 year milestone:* documented requirements of tools that support various pedagogical and theoretical approaches; tool examples that support the models.

*5 year milestone:* rules-based sequencing approaches capabilities for non-technical designers; strategies for creating “mini context” templates for reusable compound learning objects that can support many different communities of practice (e.g., secondary education, higher education, training, performance support, etc.).

*10 year milestone:* search strategies to enable “real time” assembly of content based on learner profiles, mastery, subject, etc.

### Technical Infrastructure and Management Issues

To ensure the success, long-term sustainability and widespread adoption of this undertaking, many technical, economic, social and management challenges must be addressed. Creating and supporting a virtual society that can accommodate thousands of players is an extremely complex undertaking. Aside from the issues of designing a game or virtual environment, there are important issues regarding development and maintenance of the server and application software, network connections and communications, middleware, security, and business model issues to consider. In addition, consideration of accessibility, acceptance, and adherence to organizational policies are important.

### Technology Issues

The popularity of an online game can serve as a measure of its success, but that also brings with it its own challenges. Developing and maintaining servers to

support downloads of a game or host an online environment with a CPU-intensive rendering engine introduces a special set of considerations. The cost of developing a commercial MMOG is thought to exceed ten million dollars (Snider, 2004), with nearly half of that sum attributed to development costs and the other half to marketing.

Typical MMOGs/MUVEs designs use a client/server architecture and a relational database. The server must be capable of handling a large number of connections and must be capable of updating the game or virtual environment at regular intervals without interrupting the gameplay (Lee, 2003). The servers, client systems, and bandwidth must be sufficiently robust to provide a consistent level of service for every player; while player populations can register in the millions. For example, World of Warcraft had reached over 6.6 million subscribers worldwide as of June 2006. (<http://www.worldofwarcraft.com/>) Furthermore, the infrastructure must be both reliable and flexible to cope with fluctuating demands occurring as popularity waxes and wanes over the game's lifetime. It must also be able to be updated to ensure that hardware and software is not quickly rendered obsolete and that the players do not perceive latency. The hosted infrastructure for a commercial grade MMOG requires the deployment of hundreds or even thousands of servers (Esbensen, 2005).

A key component of most MMOGs and MUVEs is the quality of the 3D graphics and perceived realism of the virtual environments. This requires sophisticated 3D graphics engines, real-time shader techniques and physics simulation. In the near future, expected widespread introduction of MMOG software engines and the creation of generic tools will enable teams to mod (modify) existing MMOGs easily or to produce their own MMOGs, but these platforms and tools are not yet available. However current MMOGs and MUVEs do not have the necessary capabilities to create environments with high-fidelity physics simulations.

Hardware and networking infrastructure (“consisting of shared clusters of game servers, database servers, proxies, content servers, and wide area network [WAN] connectivity”) should be able to be hosted in multiple locations. Bandwidth must be secured to ensure there is no lag. Servers (shards) must also be able to be removed or added while seamlessly incorporating newly added bug-fixes and content. Game-server infrastructure, tools and methods must be created that allow scalable, ubiquitous interactions for players (Dolbier and Goldschmidt, 2006) and that will be supported not only on currently available devices but those on the horizon such as the 3D home media center. Other technical infrastructure issues that should be considered include supporting multiple platforms that permit unpredictable expansions in numbers of players. Ubiquitous gameplay is a current development goal, with game experiences being delivered on multiple platforms that support PCs, consoles, handheld and mobile devices.

Hardware and networking capabilities on the end-user side is also a factor. The minimum technical requirements for some MMOGs and MUVES are beyond the capabilities of typical labs in most schools and colleges, particularly with regards to graphics cards. Games intended to reach a wide audience must balance between the high expectations gamers have for the graphics and capabilities of technology widely available in homes or school. Seeking to engage audiences in both formal and informal educational settings requires that developers consider the wide variety of specs and the lack of IT support available. Products developed or funded should have an easy download and installation routine or run on a networked server. While the US had reached at least a 98% connectivity rate in classrooms by 2000, (Cattagni and Ferris, 2001) at-risk populations still face a “digital disconnect.” Thirty-two percent of American adults do not go on line and only fifty-three percent have high-speed access required for advanced technologies such as MMOGs or persistent worlds. (Fox, 2005) Some of these problems may be short-lived as computer capabilities are increasing greatly with each new adoption cycle of desktop/laptop computers.

Content development is very important - games which aren't continually revised and updated tend to lose player interest. Initial content – virtual environment and objects and well as learning content, will need to be created. Very likely initial development will require the services of persons skilled in the use of 3D modeling tools. NASA's longer-term goal should be to provide tools and interoperable standards that will encourage user-developed content.

The persistence of data is a perennial issue for all digital materials. The integrity of the files must be ensured. Moving and reorganizing data can break links. Creating a stable place to build an audience is essential not only for continuity and sustainability, but also for protecting data for future use and ways to access it. Persistent URLs (uniform resource locators that point to an intermediate resolution service, rather than a specific location) are one possible solution. (<http://www.purl.org/>)

Security is important to protect against both malicious and non-malicious users. The software must protect the integrity of client files and prevent cheating and hacking, but must be able to verify users and allow for user-created, user-modified content.

### **Business/Funding Model**

Like the data created, the program itself needs a management plan and a secure budgetary/funding stream not only to accelerate the development, commercialization, and deployment of new generation games for learning, but to ensure the longevity of such an initiative. One business model that many MMOGs and MUVES have taken is to charge players for a subscription service. Issues associated with this model for a sustainable project include determining the

pricing structure; collecting, storing and maintaining user data; requiring payment for added features; offering premium accounts for new features and additional areas; handling cash transactions for subscriptions and services. Other funding models should be considered and evaluated.

### **Intellectual Property and Acceptable Use Policies**

Many of the legal liability issues of virtual spaces have not been resolved. Policies and agreements regarding digital rights management, licensing, patents and intellectual property issues need to be created before work is undertaken to create an interactive virtual world that permits users to share, create and store digital resources either in the form of assets or knowledge. *Second Life's*<sup>TM</sup> current policies allow a user who creates an item to retain certain rights, simulating and in some ways enhancing the real world. This approach appears to be very successful, although some copyright available issues are still to be resolved.

To support and encourage use, additions and improvements to virtual worlds, tools should be created that allow in-world content to be peer-reviewed. Policy or technologies should be introduced that ensure materials introduced into the system are accurate and are up-to-date. Strategies should be designed to report and correct technical bugs, inaccuracies and incompleteness in the content. In addition, recommender systems and rating systems could successfully be applied to promote sustainability and leverage the success demonstrated by social networking activities on the web. This technology would enable users to find similar materials and draw attention to innovative materials being developed.

### **Building a Community**

Audience is a key component in the design and implementation of a successful persistent world. Research and planning must ensure that the innovative online environment is both accessible and attractive to a wide demographic. Marketing is a critical first step to build a critical mass or community that will use and populate the virtual world. Once an audience is created, policies need to be developed to ensure that the online space offers a safe place to learn and interact with others. Rules for in-world behavior must be monitored and enforced. Disruptive players can present a problem. For classes held in publicly accessible areas, disruptive players may interfere with the learning experience and affect the student experience (Kemp, 2006).

### **Organizational Policies and Requirements**

There are a number of relevant federal laws that govern the creation and use of information. Information collections created must, for example, adhere to agency guidelines including the Paperwork Reduction and Privacy Policy (<http://www.archives.gov/federal-register/laws/paperwork-reduction/>). In addition, support and training should be provided for contributors to ensure that

special needs audiences are able to participate by making the content 508 compliant. Research and development should be undertaken to create generic tools or systematic ways to enable data and virtual experiences to be represented in ways that transcend visual or auditory perception. Examples include: improving accessibility for visually impaired students by using interfaces that work with screen readers; for students with less severe visual impairments, providing the ability to modify colors and fonts to be less stylish but more readable.

### Understanding Change in Education and Training Institutions

There is growing consensus that the slow adoption of technology in educational institutions has less to do with the technology, and much more to do with the institutions' organizational structures, instructional practices, incentives, and other systems that are strongly resistant to major change. Because they may require concomitant changes in these areas, promising technology-enabled innovations may be introduced inappropriately, if introduced at all. Research is needed to better understand the barriers to technological, organizational, and systems change in educational institutions (FAS, 2006).

Educational games and simulations are fundamentally different to the prevalent instructional paradigm. For example, games are based on challenge. Many games — such as the civilization-building games being used in some classrooms today — are not generally compatible with the traditional fixed 45-minute segmented class schedule (Squire, 2005). For example, *Civilization* takes several hours to learn and 10–20 hours to play, and could not be completed in the time span of several classes in school. This is in contrast to instructional systems geared around books, focused on taking a chapter of a book for each class period, working through it, and then doing the next chapter in the next day's class.

Furthermore, teachers have not been trained on integrating modern games and game features into their curricula, nor how to coordinate between virtual and real activities. Learners need to be able to move seamlessly among game scenarios, web-based and print resources related to concepts in the game scenarios and on-line and classroom discussion groups employing these scenarios. With much riding on the high-stakes testing associated with No Child Left Behind and state education standards, preparation for meeting these standards is the main focus of teaching. Any experimentation during school has to be sensitive to the needs and education of the children who are the experimental subjects. The school day is already fully committed, so there is little room for innovation or experimenting with new forms of instruction.

NASA can play an important role in understanding change in education and training institutions. The Agency can do this by encouraging participation in e Education projects by education and training institutions that are willing to redesign their instructional practices and formal learning environments to take advantage of the technology-enabled exploration, interactivity, and collaboration encouraged by educational games and simulations. Evaluation methodologies that



enable studies of innovation would be extremely beneficial to the broader e-learning research community.

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