Rich Interfaces for Learning Environments– 20yr Horizon

Amy Baylor (1), Gautam Biswa (2), Winslow Burleson (3), Kasia Muldner (3)
(1) National Science Foundation
(2) Electrical Engineering and Computer Science/ Computer Engineering
Vanderbilt University
(3) School of Computing, Informatics, and Decision Systems Engineering/
School of Arts, Media and Engineering

1 Introduction

In the last decade, advances in computer technology, graphics and animation, sensor technology, human computer technology, and intelligent tutoring systems has created opportunities for rich interfaces that can significantly influence the next generation of learning environments. This report investigates the current state of the art of rich interfaces for learning environments, and then outlines our vision of how research and development of these interfaces will advance over a 20year horizon. In particular, we believe that these interfaces of the future will play a central role in defining key characteristics, such as choice-adaptivity, ubiquity and wide accessibility, and support for lifelong learning in systems of the future.

New and exciting technologies provide the framework for developing rich open-ended learning environments than combine a number of different learning paradigms and resources [refs]. Students can complete quests in game environments [ref], engage in inquiry in realistic mixed reality environments [ref], interact with virtual agents [ref], run science simulations [ref], work in problem solving environments guided by a tutor [ref], access the web [ref], and more generally make choices about different learning activities. A basic insight is that these choices can be extremely informative about student learning and diagnostic of how students learn in formal and informal learning situations. Further, rich interfaces provide mechanisms for mining student choices in relatively open learning environments to determine whether students are showing (sub) optimal patterns of learning [refs]. The environment can then adapt intelligently by encouraging (alternative) choices. Ideally, by permitting student choice, while at the same time providing adaptive metacognitive and meta-affective support for making better choices, we can help learners develop effective choices of what, when, and how to learn.

Technology has also progressing in ways that learners now have access to a variety of learning resources through connected networks of learning management and educational systems, with some individual support in accessing learning resources, taking part in formal and informal learning activities, and having opportunities to interact with peers and mentors [refs]. The next generation of these widely accessible ubiquitous learning environments must develop a new generation of rich interfaces that provide interoperability, and a seamless approach to bringing together learning content, personalized learning services, and the availability of a host of learning collaborators that span mentors, tutors, peers, and helpers.

The provision of lifelong learning facilities that transcends traditional educational institutions (K-12 and university) and begins to impact aspects of continuing education and professional development as well as how to cope with changing situations in one's society and environment is a major new direction that greatly expands the role of rich interfaces and learning environments [refs]. Content, delivery, personalization, and choice adaptivity in the future will have to support seamless, ubiquitous access to lifelong learning facilities at home, at work, in schools and universities. This implies the development of new ways of organizing learning delivery that that goes beyond course and program centric models to flexible and adaptive learner-centered, learner-controlled models of distributed lifelong learning.

2 Dimensions of Rich Interfaces:

A central component in these vastly expanded learning environments of the future are rich interfaces, whose scope extends over multiple dimensions, illustrated in the figure 1.

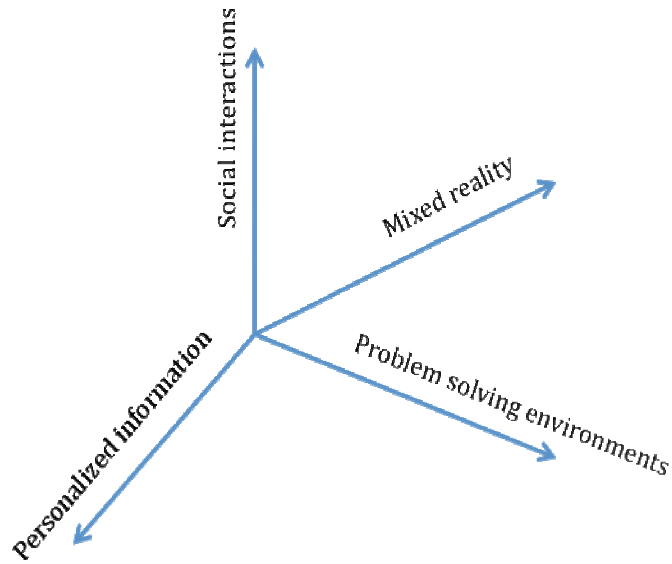

Figure 1: Learning environments of the future include Rich Interface with multiple dimensions.

These
dimensions may be characterized as:

- Problem solving environments that span a wide variety of learning paradigms, such as intelligent tutors, exploratory simulations, multi-user collaborative systems, and game environments.
- Social interactions that include multiple modalities, such as one on one intelligent tutors, virtual agents with multiple roles (e.g., mentors, peers, learning companions, and teachable agents), and human to human interactions mediated through technology,
- Personalized interaction, that attends to motivation, self-efficacy, and affect using adaptive media, information, and user models.
- Mixed reality, the nature of learner-system interactions ranging from purely physical to purely virtual environments, and those that include both.

In general, these dimensions are not independent or mutually exclusive, but they provide a useful framework for characterizing research directions that will individually and collectively contribute to the design, analysis, and evaluation of the effectiveness of rich interfaces.

3 Vision/Outcomes: The Impact of Rich Interfaces

Our vision for the outcomes and impact of rich interfaces is that through synergistic forms of traditional and immersive project-based learning experiences a new form of learning environment will emerge with the following outcomes:

- Blurring formal – informal learning: we expect to see bluring of formal and informal learning in two ways. First, the tools and resources used in formal environments will become widely available and that these tools will transition seamlessly between formal to informal environments. Emerging examples of this phenomenon exist in the form of LEGO Mindstorms robotics interfaces that are used in formal and informal education in museums, classrooms, homes, and play. Likewise, the Scratch-programming environment (http://scratch.mit.edu/) is offering tools that span formal and informal environments. The second manner in which we expect to see blurring of formal and informal learning environments is the seamless transition of learners and learners' abilities to transition, transfer, apply, and enhance their knowledge, experience, and discovery and imaginative inquiry across these environments.
- Enhancing social - motivational interactions: we expect rich interfaces to provide new opportunities for social and motivational interactions that facilitate learning. Already we are seeing emerging Intelligent Tutoring Systems with Affective Learning Companions that are beginning to become capable at sensing and responding appropriately to elements of learners' emotional and motivational states. These systems are leading to **all learners having the opportunity for one-on-one personalized instruction**. We see new opportunities emerging from multiple learning companions in many forms – as embodied, ambient, and embedded virtual agents; as co-located and distributed human peers and mentors; as community members, teachers, and parents, each enhanced by information from rich interfaces and diverse sources of guidance for providing actualizing social and motivational feedback opportunities and interactions.
- Multiples perspectives and roles for teachers: we expect teachers to continue to be of primary importance in school environment and to extend thier significance to informal settings as well. Their influences will likely increase as their abilities to interact with students in broader and more diverse contexts increase. We see teachers participating in administrative, participatory, and pedagogic roles. As administrators, rich interfaces will provide teachers new and more accurate forms of information about individual and group learning, motivation, social activity, and opportunities. These will enable teachers to respond more effectively to a greater range of needs of the increasingly diverse learners they interact with. As participants, teachers will frequently engage side-by-side students, as members of project teams and at times as followers of student leaders (see Section 6: Scenarios). In their pedagogic roles, teachers will have more tailored and higher quality information to inform their actions and a greater range of actions will be afforded them. Teachers interacting with special needs children will have ready access and specific guidance from the latest and best strategies for their specific students, stemming from advances in educational psychology. These technologies will also empower teachers with new tools and targeted opportunities to directly apply these advanced theories, e.g. understanding Dweck's message, that the mind is like a muscle and that even though the task may be frustrating, sticking with it may be a learning opportunity, and when to apply it).
- Multiple perspectives and roles for students: we, likewise, expect students to engage in diverse participatory roles, as leaders, followers, public speakers, listeners, integrators, decision makers, supporters, contributors, etc. One particular role that is likely to increase is students' pedagogical role. As teachers, they will not only be solidifying and expanding their learning they will also be contributing to their peers and increasing their social skills and networks. These roles will span the formal and informal environments.

- Enhancing Creativity, Curiosity, and Intrinsic Motivation: we expect increased opportunities for engaging in and supporting creativity through personal constructionist project-based activities that apply Shneiderman's framework of using information technology to collect, relate, create, and donate.
- Longitudinal and lifelong: just as we expect these interfaces to permeate throughout life experiences, we expect rich interfaces will support life long learning (longitudinal), and ubiquitous (embedded) experiences. These persistent interfaces will adapt to learners across life transitions and stages. In many ways they may come to know the learners better then the learners themselves. As a tool they will be there to enhance and facilitate the learner's life aspirations, reflections, and engagements.
- Rich experience, reflection, analysis, and theory development: most of all we expect rich interfaces to lead to rich experiences that incorporate opportunities for learners to reflect on their own learning. Likewise learning scientists will have new opportunities to analyze vast new data sets, collected from the rich interfaces, that contain elements of learning, affect, motivation, social interaction, and longitudinal, indeed life-long data and patterns of learning and engagement that will no doubt lead to new theory development with powerful impacts.

As the world and the challenges society faces becomes increasing complex we see the need and opportunities for rich interfaces, new forms of learning and social and creative interaction as paramount to societies' success. Today, many students succeed yet many others fail; we believe all learners have the potential to be more successful, and that rich interfaces will play an important role in both helping individuals be more successful and in helping advance learning science. If we do not adopt the new strategies afforded by rich interfaces even the students succeeding today will likely fail to meet tomorrow's challenges. Thus, these rich interface tools and learning environments provide not only the opportunity to extend the success of today's and tomorrow's successful students, but also the promise of increasing the success rate, providing education and opportunity for all learners.

4 Meta-Cognition and Meta Affect

Through rich interfaces and the information they provide, these new learning environments have the capability and responsibility to provide learners with a full range of experiences and engagements that continually adapt and equip learners with diverse resources and skills. These environments will help learners: attend to their engagements; engage in reflective thinking and pursuits; and envision, plan, and pursue their desired futures.

In a world that in increasingly grappling with information overload, with multiple interfaces and opportunities vying for learners attention, rich interfaces must be developed in ways that provide learners with tools and skills that enable them to personally tailor their environments, so that they can focus their attention and attend to their engagements.

An important element of these adaptive systems will be to encourage learners to engage in reflective thinking and pursuits, applying lessons and facilitating skills from the fields of meta-cognition and meta-affect (being aware of ones own affective state, its benefits and detriments, and skilled at applying appropriate responsive strategies) and from Shoen's Reflective Practitioner and Atman's work on education and reflection, among others.

The longitudinal nature of rich interfaces provide a unique opportunity and tool, not only to better understand and facilitate learners attention to their engagements and reflective thinking, but also to ground and promote their ability to envision, plan, and pursue their desired futures. These tools will literally provide direct exploration opportunities of diverse possible futures, consequences and benefits, and guide learners in the preparation and commitment to their plans for pursuing them. Rich interfaces can serve as self-actualizing technologies [Burleson 2005].

5 Advancing the State of Rich Interfaces

Traditionally, an example of a "rich interface" has been one that includes a virtual agent that aims, for example, to improve learning through tailored tutorial dialog. However, as is evident throughout this document, we believe that the concept of a rich interface needs to be broadened to include a wider range of aspects spanning the virtual and physical realm, such as, rich virtual environments that include both human and virtual players, for instance in life-long games (Burleson'09, GALLAG); classrooms supplemented with specialized distributed virtual and physical simulations that foster curiosity and instruction through inquiry based learning (moher'08); and robots that are increasingly socially expressive aimed at fostering learning (Personal Robots, MIT Media Lab). We believe these interfaces will be integrated throughout most aspects of learners' lives.

Table 1: Sample capabilities of rich interface elements today and (predicted) 20-Year from now.

Rich Interface	CURRENT STATE	20YR FUTURE
Affective, emotion, motivation	Limited sensing/expression Cumbersome	Strong recognition, fluent expression and highly personalized
Embodied interaction	Limited mirroring Encumbered joint analysis	Full body capture everywhere
Learning companions	Virtual characters embedded in desktop systems	Virtual + robotic companions that seamlessly switch between virtual and physical settings
BCI	EEG / Near Infra Red	Continuous wearable fMRI-like capability
Physiological	HR/ Breath	in-body monitoring and transmission – oxygen, glucose and cortisol indicators
Augmented Reality	Difficult registration, limited resolution	Seamless, natural, ubiquitous [Ref World board]
Haptic	Limited low resolution, high power haptic capabilities	Enhanced Mobility Supper Hero Capability

While a given component of a rich interface does not necessarily need to be "intelligent", we propose that in order for a rich interface to provide appropriate pedagogical support, overall the system does need to be intelligent, and consequently, rely on sophisticated Artificial Intelligence techniques and sensing devices. In particular, sensing devices play a key role in rich interface functionality, in that they have the capability to capture information on user's states of interest, such as her goals, expertise, affect and preferences; this information subsequently can be used to (1) generate an assessment of the user and (2) tailor the interaction to a given user's needs. While assessment is the focus of the Assessment group led by Val Shute also in this report, we highlight here the integral role rich interfaces play in facilitating assessment. The sensing devices, and tailored interactive environments, enable unobtrusive assessment, by capturing data as a natural by-product of users' interactions with the systems, instead of interrupting the user to ask her directly. Unobtrusive assessment is one area where technological advances have begun and one in which we expect to see more significant advances.

Current State: Table 1 summarizes the current and future state of rich interfaces. As the table demonstrates, today's technologies have begun to take advantage of recent advances in sensing and computational capabilities. For instance, rich interfaces exist incorporating agents that engage users in non-verbal communication and gaze and gesture. To accomplish this, the agents rely on a complex sensing framework that captures users' physiological responses and uses this data to infer their affective states. Clearly, sensing affect is both a challenging endeavor and a key one in order to provide users with a holistic experience during various forms of instruction.

Future of Rich Interfaces: Our twenty-year vision for rich interfaces supporting learning is that foremost, these interfaces will not be constrained to virtual desktops in students' classrooms, but rather will expand into learners' environments, effectively delivering ubiquitous instruction – any time and anywhere. These interfaces will address all factors that influence learning, including not only domain-related traditional feedback, but also sleep hygiene, exercise and mental health, to name only a few.

As far as capturing user-relevant information, we anticipate transformative advances in sensing devices, as are summarized in Table 1, that will allow these interfaces to seamlessly capture user-relevant information and adapt to the user's needs in order to maximize learning outcomes and adapt to and interact with motivation and affect. These sensing devices will take advantage of the full spectrum of physiological data in order to maximize system ability to appropriately tailor to individual users.

As far as subsequently relying on user information to respond appropriately to a user, we anticipate that future interfaces will leverage a broad array of feedback techniques, including haptic, natural speech, novel interaction techniques and virtual simulation. These interfaces will go beyond the traditional tutor model to include learning peers, i.e., holistic friends encouraging life-long learning though motivational tactics and curiosity promotion.

Currently, most interfaces focus on students in their early life stages, and do not sufficiently involve teachers in the design or instruction delivery process. Rich interfaces will remedy these limitations, by providing support for (1) life-long learning, as we illustrate through scenarios in Section 6 and (2) a wide range of tools for teachers, including the ability to tailor the instructional content and access to student assessment records.

6 Scenarios: Today and in the Future

In this section we present two scenarios chosen to show the current and anticipated states and opportunities for rich interfaces in formal and informal environments at diverse life stages. Each one is presented in two timeframes, today and in the future.

Scenario 1: Serious Games – Astronaut Robot Mission Simulator:
In what is arguably the most advanced college classroom in the world, ASU's School for Earth and Space Exploration, the School of Computing, Informatics, and Decision Systems Engineering, and the School of Arts, Media and Engineering are developing a Game As Life – Life As Game [Ref] based Astronaut Robot Mission Simulator (ARMS) [Ref Sandbox]. This rich interface-learning environment consists of a 270-degree rear projected environment in which 10 class sessions were held throughout the Fall 2007 and Fall 2008 semesters. The rich interfaces and scenario is geared toward planetary exploration and the study of mission contingencies. These engage a transdisciplinary course involving 45 students ranging from 2nd year to graduate students collaborating to plan a lunar mission.

Figure 2: ASU's Decision Theater interactions with ARMS's virtual Apollo 15 landing site and MIT's Path Planning Software.

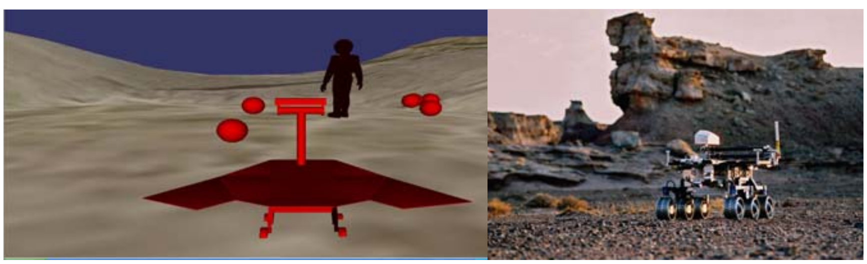

Figure 3: Remote participants' OSG view of Astronaut Robot Mission Simulator (ARMS) with navigational waypoints and Robot in real-world Mars Analog Environment.

A particular focus of these contingencies (e.g., loss of communication or power, injury, solar flare) is their impact on the optimal return of scientific data with respect to the resources expended. An Open-Scene-Graph (OSG) environment manages the immersive planetary environments and presents them to both co-located and distributed participants. The OSG environment supports multiple representations of astronauts, rovers, and ambient data within high-fidelity planetary environments. The environments that have been incorporated to date include the digital elevation model (DEM) of the Apollo 15 lunar landing site, the Jet Propulsion Laboratory's Mars Yard, and Mount Everest. The ambient data within these environments has included the status of the astronauts and rovers, navigational trails and waypoints, projected scientific data, and various filters that enable augmented reality like visualizations of planetary environments and their features (as they relate to scientific value, safety hazards, parameters of human-robot collaboration, etc.). An OSG environment rendered within ASU's Decision Theater, a 270-degree rear-projected environment (similar to a CAVE), supports, at any given time, 25-30 co-located participants and many more distributed participants. The OSG environment has been linked, through high-resolution global positioning systems (GPS) and radar-reflection positioning systems and physiological data (e.g., heart rate and respiration), to remote participants (robots and "astronauts") at the Jet Propulsion Laboratory (JPL) and at MIT's Field and Space Robotics Lab and MIT's

Manned Vehicle Lab. The GALLAG/ARMS architecture has also been linked to JPL's robot and planetary simulation software ROAMS and SimScape and their real-time physics and soil-dynamics modeling engines. Bi-directional communication between all participants has been realized via UDP, TCP, Skype, and Polycom video conferencing.

The noted computer scientist and educator, Alan Kay, said " the best way to predict the future is to invent it". We are using today's advanced rich interfaces to explore the potential of these tools and environments to advance learning and science. Through the seamless connection of research and education we are providing students with opportunities to work in a large-scale team (45 students) and to take-on diverse roles in a lunar mission. We are advancing project-based learning across formal (in class) and informal environments (working groups). Wearable and on-line tools, e.g. blogs and smart badges [Ref], are starting to provide assessment of individual involvement and group cohesion. These tools and scenarios enable instructors to become part of the team processes. Connecting with a diverse community of remote experts further enhances the validity and learning opportunities.

20-years from now: while today's scenario involved college students and high tech, in the future a distributed team of elementary students from a range of ages might interact with mobile technologies from home or classrooms with mentors, experts, and teachers. Their mission scenarios might involve the physiological responses of their team members as they engage in field geology and interact with co-located and distributed robots. The fatigue rate, and thus mission safety parameters, may be linked to the sleep hygiene of the student, over the previous week. Likewise their liquid and caloric intake may be monitored and may drive elements of the mission. Online virtual observatories will provide real-time solar monitoring provide data on solar flares that will likewise be integrated. In fact, one or more members of their team may in fact be on the surface of the moon. The robots on the moon may at times be responsive to the best mission scenarios. Similar teams around the world may be involved in optimizing scientific return and competing and collaborating in strategies for lunar exploration that are in fact better than the ones that are developed by space agency scientists, alone. Other missions, to the oceans, rainforests, urban centers, and nano-space will expand the understanding and learning opportunities for all who are interested. Those most interested may continue to engage in lifelong scenarios that ultimately take them to the lunar environment, or immerse them as experts in nano-space collaborations.

Throughout the mission(s) students will have opportunities to lead and to become better leaders by learning how to be good followers, too. For learners who are less engaged, frustrated, angry or more interested in other activates their personalized learning companions and teams will tailor their interfaces appropriately. A rich history of personal data and experiences will provide strong understanding of effective personal strategies and learning objectives. Teachers will likewise be equipped with tools that allow them to be aware of learner's needs and interests and to engage and facilitate them.

Scenario 2: Kitchen – Informal / Lifelong

Today: Dave decides to a make up a new French fish recipe. He starts by searching online for ideas –he pulls up four or five that sound interesting, reads them and decides to borrow bits and pieces from each one. The final recipe will include a Hollandaise sauce made from scratch. Dave grabs his laptop, props it on the kitchen table and begins to assemble ingredients and doing the prep (chopping onions, garlic and herbs, prepping veggies, marinating fish etc). As he works he has to intermittently check the recipes on the laptop. He puts the fish in the oven, only to realize he forgot to preheat it – he pulls it out and waits out the preheating. When it's ready, he puts the fish in the oven. In the meantime, he starts on the Hollandaise sauce. This involves a delicate balance of whipping egg yolks over a low heat, heating butter, and adding it to the sauce carefully so the sauce does not separate. Dave doesn't realize that the sauce isn't supposed to get too hot in this process and it does separate – he has to start again.

20-years from now: Dave decides to a make up a new French fish recipe. He walks into his kitchen and asks his virtual chef agent for ideas. This agent pulls up several recipes that sound interesting; Dave and the agent discuss the merits of each recipe and decide on a final one that the agent displays for Dave by projecting it over the cooking work area. The final recipe will include a Hollandaise sauce made from scratch. Dave begins to assemble ingredients and doing the prep (chopping onions, garlic and herbs, prepping veggies, marinating fish etc). As he works, the chef agent gives him tips related to, for instance chopping technique, reminders on ingredients he needs, to preheat the oven etc. Dave puts the fish in the oven; in response, the timer sets itself for 35 minutes; he now starts on the Hollandaise sauce. This involves a delicate balance of whipping egg yolks over a low heat, heating butter, and adding it to the sauce carefully so that the sauce does not separate. As he works, the chef agent monitors the sauce temperature and warns him when the temperature gets too hot, so that the sauce does not separate.

7 Time Frame Research Strategy

We will now present time frames, 2 years, 5 years and 10years from now, with expected opportunities and strategies:

In the 2-year time frame we see opportunities to apply the current best practices from the current theories of learning and human computer interaction. We see applications that use existing rich interfaces (see table 1), including: mobile phones, tablets, commercially available and research grade physiological and affective sensors which are beginning to be deployed in classrooms.

Available Technologies to Sense, Analyze and Recognize:
•Sensors: RFID, Speech Technologies, GPS, Smart Phone, Camera (self cam, external cam), longitudinal and comprehensive logging (MSR Vibe logger, socio-scopes).
•Virtual Agents: can be embodied and robotic; current low-cost and end-user deployable responsive environments (e.g. GALLAG) can be deployed in classrooms and homes; agents can be presented as peers and offer engaging social support and advanced scaffolding.

In the 5-year time frame we see opportunities to advance theory with data and experience collected from the deployment of rich interfaces in the 0-5 year time frame. We see new opportunities for broader deployment of today's emerging technologies, e.g. wide spread use of smart phones with GPS, cameras, multi-party mobile communication, extension of sensors into the home and greater capacity for longitudinal applications.

In the 10-year time frame we see a much stronger understanding of the opportunities, potential, limitations, and grand challenges of rich interfaces for learning environments. We also see new understanding for the evaluation of these environments across formal and informal experiences and longitudinally. Several cutting edge technologies will likely be ready to be broadly deployed, including new interfaces for full body interaction, a broader range of wearable technology for physiological sensing (e.g. low cost wireless EEG) and heads up augmented reality.

Throughout these time frames we see the need and opportunity to test and explore diverse technology presentations and paradigms, including:

•Experiences, scenarios, projects: rich interfaces offer terrific and limitless opportunities for developing new and ubiquitous experiences for learning. Diverse scenarios, topics, social structures and engagements must be explored. Project based learning seems to be one of today's best opportunities for blending formal and informal learning opportunities and for beginning to explore longitudinal deployments. Likewise social structures can often be readily adaptive within projects.
•Gaming: both current explorations of serious games and classroom game design and programming activities as well as emerging paradigms for augmented reality (Mohr) and lifelong gaming (Burleson 2009) offer new opportunities to advance mixed reality systems and to explore diverse rule-based paradigms, their consequences, benefits, and outcomes.
•Simulation: provides opportunities for immersive understanding and adaptive exploration of divers real world and constructed environments that afford a wide range of exploration opportunities, ranging from the scientific to the social and artistic.
•Intelligent Tutoring Systems (cognitive tutors, pedagogical, teachable agents, etc.): these systems are currently some of the most advanced rich interfaces and they will continue to be a driving force. We expect them to expand in all of the same ways that we have discussed rich interfaces, expanding, e.g. formal/informal, social, motivational, longitudinal, etc.
•Embodied, situated cognition and mind-body learning: rich interfaces and tangible media provide compelling opportunities to expand the important role of these learning modalities. We expect embedded technologies and advances in ubiquitous computing and responsive environments to be a major contributor to the deployment modalities for rich interfaces.
•Exploratory environment (sandbox): we are strong advocates of providing learners open exploratory environments that stimulate curiosity, exploration, and creativity, and believe that rich interfaces and participatory design strategies can make important contributions in this domain.
•Holodeck for Formal/Informal Instructions: the paradigm of the Holodeck a fully adaptive rich interface environment is compelling and will continue to be advanced.
•Teacher and Mentors: we believe rich interfaces and their diverse deployment scenarios offer learners and teachers new developmental opportunities to participate in diverse roles that will enhance both their learning and teaching abilities. We also see the role of teachers as guiding the course of learning for individuals and groups, as guru's, apprentices, and skippers.

8 Proposal Recommendations

In conclusion our recommendations for solicitations that seek to advance rich interfaces for learning environments should address both the advancement of theory and the application of existing theory and emerging and existing technology in real-world settings, e.g. classrooms and homes. We believe that researchers advancing rich interfaces for learning environments must commit to developing new contributions to **theory** (advancing the science of rich interfaces) and **application** (the integration and leveraging of new and existing sensors) seamlessly across formal and informal learning environments and longitudinally, to promote actualizing, holistic, and lifelong learning experiences for all.