Innovative Media in Support of Distributed Intelligence and Lifelong Learning

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Abstract

Individual, unaided human abilities are constrained. Media have helped us to transcend boundaries in thinking, working, learning, and collaborating by supporting *distributed intelligence*. Wireless and mobile technologies provide new opportunities for empowering humans, but not without potential pitfalls.

We explore these opportunities and pitfalls from a *lifelong-learning* perspective and discuss how wireless and mobile technologies can influence and change conceptual frameworks such as the relationship between planning and situated action, context awareness, human attention, distances in collaborative design activities, and the trade-off between *tools for living* and *tools for learning*.

The impact of wireless and mobile technologies is illustrated with our research projects, which focus on moving *"computing off the desktop"* by *"going small, large, and everywhere."* Specific examples include human-centered public transportation systems, collaborative design, and information sharing with smart physical objects.

1 Introduction

A fundamental challenge for research in computer science, cognitive science, and the learning sciences is to understand thinking, learning, working, and collaborating by exploiting the power of omnipotent and omniscient technology based on reliable, ubiquitous wireless and mobile computing environments. New ways of thinking and new educational approaches are needed to address the design of socio-technical environments [Mumford, 1987]. We need to understand what tasks should be reserved for educated human minds and the collaboration among different human minds, and what tasks can and should be taken over or aided by cognitive artifacts. In such an information-rich world, the true power comes not from more information, but from information that is personally meaningful, relevant to people's concerns, and relevant to the task at hand.

2 Challenges for Education of the Future

We first discuss challenges for education of the future, focusing on issues around lifelong learning and distributed intelligence.

Lifelong Learning. Our approach to lifelong learning is grounded in a *basic assumption:* If the world of working and living relies on collaboration, creativity, definition and framing of problems, dealing with uncertainty, change, and distributed cognition — then education needs to prepare students for meaningful and productive lives in such a world. Education from a lifelong learning perspective *should help learners enhance their abilities to learn, engage in meaningful activities, exploit the power of media, and promote new civic discourses*, since a major role for new technologies is not to deliver predigested information but to provide for social debate and discussion [Bruner, 1996]. Wireless and mobile technologies provide an important step toward lifelong learning that supports learning anywhere at any time throughout one's life [Sharples, 2000].

Distributed Intelligence. We need to gain a deeper understanding of how *distributed intelligence* [Hollan et al., 2001; Salomon, 1993] can make fundamental contributions to the future of education, learning, and the development and use of new media. In most traditional approaches to such research, *human cognition* has been seen as existing solely "inside" a person's head, and studies on cognition have often disregarded the physical and social surroundings in which cognition takes place. *Distributed intelligence* provides an effective theoretical framework for understanding what humans can achieve and how artifacts, tools, and socio-technical environments can be designed and evaluated to empower human beings and to change tasks [Norman, 1993].

To address these challenges, wireless and mobile technologies should not be perceived simply as add-ons to existing practices but as catalysts for fundamentally rethinking what education and learning should be and could be in the 21st century.

3 Wireless and Mobile Technologies: Understanding How Usage and Activity Unfold

Our research efforts, which have focused on a human-centric perspective and co-evolution, have emphasized the importance of usage and activity rather than technologies. The following questions have served as guiding principles for our research efforts:

1) *Who* is using the computer? — learners, teachers, skilled professionals, technically sophisticated users, domain workers
2) *What* are they doing? — moving through space, accessing information, engaging in informed participation and collaborative knowledge construction, communicating with others, participating in collaborative design activities
3) *Where* are they doing it? — in classrooms, in their work environments
4) *When* are they are able to do it? — at any time without major preparations or setup;
5) *Why* are they doing it? — a self-directed and self-motivated activity, an assigned task, to obtain information
6) *How* do they it? — in a tool-rich environment, in their heads

Transcending the Unaided, Individual Human Mind. Our research has identified and explored a fundamental distinction about distributed intelligence and the change of tasks in a tool-rich world by identifying two major design perspectives [Carmien & Fischer, 2005; Pea, 2004]:

- *tools for living* (such as eyeglasses) are grounded in a *distributed intelligence* perspective, in which intelligence is mediated by tools for achieving activities that would be error prone, challenging, or impossible to achieve
- *tools for learning* (such as training wheels) are grounded in a *"scaffolding with fading"* perspective in which the ultimate goal is autonomous performance by people without tools.

This distinction raises the fundamental question concerning what it means to learn in the 21st century in which powerful tools are available "anywhere at any time" for many intellectual activities—allowing people to have instant access to facts, assisting people in spelling, doing arithmetic, memorizing experiences, making sense of a large amount of information, connecting and collaborating with others, and performing numerous other intellectual activities.

Tools for living rely on the presence of the tools at all times, and wireless and mobile technologies can therefore make them more relevant because we can rely on them at all times.

Planning and Situated Action. Technologies that allow for accessing and using any information, any place, at any time may eliminate the need to plan ahead for something we can make better decisions about when the event is actually taking place [Brown et al., 1989; Suchman, 1987].

For example, train and bus schedules now can often be accessed on mobile phones, eliminating the need to plan and fix an itinerary *before* traveling. Wireless and mobile technologies (such as route planners and car guidance systems) are changing the skills needed to be a smart traveler by shifting the focus from smart planning to smart situated actions.

Context Awareness. Determining the context for an individual located somewhere or a group distributed all over the world is a substantially more difficult problem then for people gathered in an office or a classroom. Interactions with computational artifacts are often part of a larger activity, such as a complex design task, but computer systems do not "understand" the larger activity. Building truly context-aware learning environments [Ogata & Yano, 2004a; Ogata & Yano, 2004b] presents a greater challenge than using data transmitted by wireless and mobile computing devices (such as GPS, RFID, and other sensors); it requires shared understanding between humans and their computational environments [Dey et al., 2001].

Our research explores the unique possibilities of environments that model and represent domains, tasks, design guidelines, solutions and their rationale, and the larger context of such environments being *embedded in the physical world*. A key requirement for context-aware applications is the basic assumption that the *"interaction between people and computers requires essentially the same interpretive work that characterizes interaction between people"* [Suchman, 1987]. This assumption raises the following interesting challenges: (1) How can we capture the larger (often unarticulated and dynamic) context of what users are doing (especially beyond the direct interaction with the computer system)? (2) How can we increase the richness of resources available for computer programs to understand their uses (or what they are told about their users) and to infer from what they are observing their users doing (inside the computational environment and outside) [Horvitz et al., 1999]?

In design, a large fraction of context-relevant information cannot be inferred from the environment because the context resides outside the environment, is unarticulated, or exists only in the head of a designer. Without access to the stakeholders' intentions, a system is unable to detect that problems exist. If a system provides mechanisms to articulate intentions explicitly (e.g., using a specification component [Nakakoji, 1993]), and designers are willing to do so, the additional context can be used to identify the breakdown situation and provide designers with opportunities for reflection and learning. This issue has certain implications for wireless mobile applications. In particular, it highlights the significance of the approach that blends fully automated context sensing and lightweight, manual context specification.

The Scarce Resource: Human Attention. Herbert Simon [Simon, 1996] has argued that *"What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate efficiently among the overabundance of information sources that might consume it."* The challenge of future computer systems is therefore not to provide information "*any time and anywhere*," but to "*say the 'right' thing at the 'right' time in the 'right' way to the 'right' person,*" which requires context-aware environments. Without some awareness of the tasks users are performing, and without some "understanding" of the knowledge background of the users with respect to these tasks, computational environments (and human collaborators) can make only limited determinations of the relevance of information. An example of a *context-unaware* technology is Microsoft's Tip-of-the-Day [Fischer, 2001b], which presents a randomly chosen tip to the users, but makes no attempt to make the information relevant to a problem the user is actually experiencing.

4 Research Exploring Distributed Intelligence and Lifelong Learning

Over the last decade, the Center for LifeLong Learning and Design [L3D, 2005] has developed a research agenda focused on distributed intelligence and lifelong learning. Our fundamental assumptions and objectives relevant to the framework of this paper are:

1) Focusing on *Intelligence Augmentation* (IA) rather than on Artificial Intelligence (AI) by empowering human beings rather than replacing them [Fischer & Nakakoji, 1992; Terveen, 1995];
2) Providing support not only to individuals but to groups and communities, and thereby exploiting the power of social creativity based on informed participation [Fischer et al., 2005];
3) Contextualizing generic systems to person- and task-specific environments to account for a "universe of one" by supporting meta-design, customization, and end-user development [Fischer, 2001a; Fischer, 2001b];
4) Transcending "*gift-wrapping*" and "*techno-determinism*" as isolated and one-sided design objectives for new media by pursuing *co-evolution* between (i) new media; (ii) new theories about working, learning, and collaborating; and (iii) the creation of a new learning organization in a synergistic approach [Brown & Duguid, 2000; Fischer, 1998; Roschelle, 2003].

In the context of these fundamental assumptions and objectives, we have explored *"computing off the desktop"* in three different directions [Fischer et al., 2004]:

1) *going small:* socio-technical environments supported by personalized, portable devices and wireless communication that afford information and communication between people as they move around in the world — the specific application context being the *Mobility-for-All* project (see section 5.1);
2) *going large:* large computational tables that allow people from diverse backgrounds to access, contribute to, and interact with information in an inherently social manner to support collaborative work among others in shared physical locations — the specific application context being the *Envisionment and Discovery Collaboratory* (see section 5.2);
3) *going everywhere:* smart physical objects that communicate with computational environments, allow for context-aware information delivery, and create articulate environments — the specific application context being the *QueryLens* system (see section 5.3).

5 Application Systems

Wireless and mobile technologies influence how issues related to our research agenda come into play in a specific application domain. This section introduces three application systems that we have developed in our research center, and discusses their implications for designing future socio-technical environments with innovative wireless and mobile technologies.

5.1 Going Small

The *Mobility-for-All project* [Carmien et al., 2005; Sullivan & Fischer, 2003] is exploring wireless mobile technologies and architectures that lower barriers to community access and independence for persons with cognitive disabilities

To use current public transportation, it is necessary to comprehend, manipulate, and process essential navigation artifacts (i.e., maps, schedules, landmarks, labels and signs, and clocks) often encoded in difficult-to-understand representations. An increasing number of travelers are now using Web-based information services to search for optimal schedules, print maps, and acquire other essential knowledge needed to *plan* trips. Wireless and mobile technologies are further impacting travelers' practices by making resources and tools that used to be available only prior to travel also available during travel.

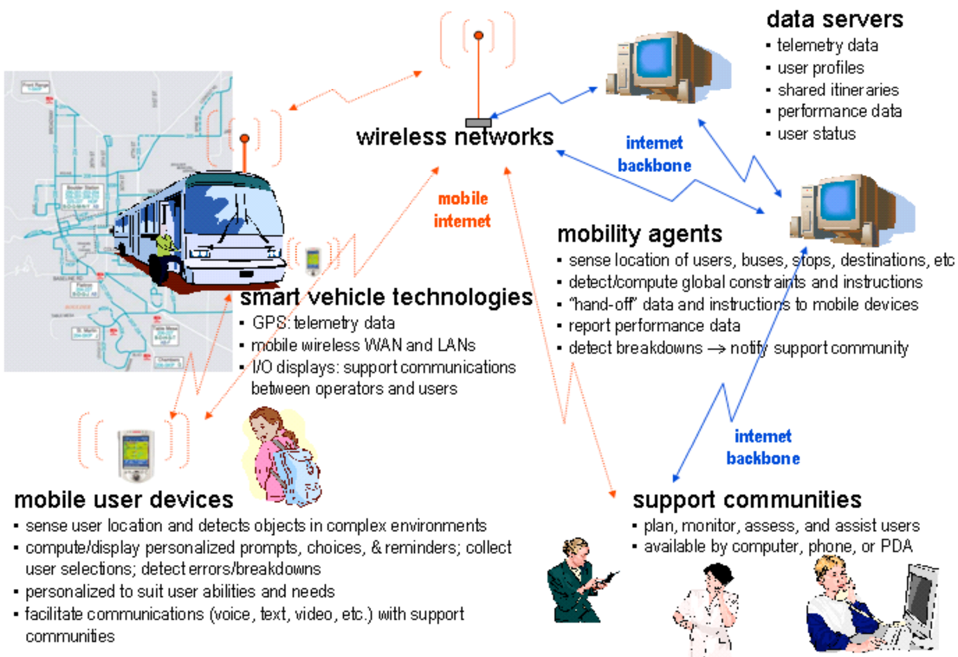

Figure 1: A socio-technical architecture to support mobile users and their support communities on transportation systems

One of the objectives of the *Mobility-for-All* project is to *devise architectures and technologies that eliminate the need to master complex navigational artifacts*. This work has been guided in large part by the distributed intelligence framework. The project's design approach was inspired by observations of instructors who accompanied new students during training sessions and provided personally contextualized, "just-in-time" instructions for what to do and where to go next. To reduce the workload on support communities, the project team considered how technologies could be designed to assist persons in their care as they traveled or learned a new route. Our success with these approaches suggests a potential of similar approaches for designing wireless and mobile technologies and the need to consider broader communities beyond students and teachers in creating a distributed intelligence environment.

The socio-technical architecture shown in Figure 1 was designed to address the needs of mobile users traveling to and from a group home facility in a community setting. This architecture leverages two emerging ubiquitous technologies: (1) wireless, mobile, location-aware personal digital assistants (PDAs) or cellular phones, and (2) mobile GPS technology available as standard equipment on an increasing number of public transit vehicles.

This architecture supports the following goals:

- Direct support of the mobile user with personally relevant navigational tasks, including selecting a destination, locating the right bus, preparing to board, boarding the bus; signaling the driver where to stop, and disembarking;
- When needed, initiate or facilitate communications between the mobile user, support communities, and transportation system operators;

- Provide a "safety net" when something "goes wrong".

These areas of system support are relevant to most wireless and mobile systems including educational applications.

5.2 Going Large

The *Envisionment and Discovery Collaboratory (EDC)* [Arias et al., 2001] supports face-to-face collaboration in complex collaborative design activities, such as urban planning, emergence management, and design of learning environments. EDC provides the affordance and the mobility that conventional desktop computer-based systems cannot support. Face-to-face collaboration, grounded by the large, computationally enhanced physical boards and design objects (see Figure 2), is critical in building a shared understanding among stakeholders with different backgrounds. Manipulations of physical objects of the EDC are sensed wirelessly by the board and fed to an underlying computational model; therefore, the EDC is able to provide dynamic feedback and relevant background information to stakeholders, extend passive technologies for face-to-face collaboration and open fundamental new research challenges and opportunities.

Figure 2: The EDC

The architecture of the EDC supports reflection-in-action [Schön, 1983] with the following components:

- The *action space* supports collaboration around the table through a physical and computational model appropriate for the particular application domain.
- The *reflection space* supports the capture, creation, presentation, and modification of hypermedia information and provides a portal to a dynamic, user-extensible, emergent Web-based information environment.
- Knowledge-based mechanisms, such as *computational critics*, contextualize information by finding information in the reflection space that is relevant to a specific event or situation occurring in the action space.

In addition to supporting face-to-face collaboration, the EDC is a rich environment for studying distances in collaborative design [Fischer, 2005]:

- *Spatial distance* is supported in the EDC. Because reflection spaces are accessible via the Web, questionnaires, discussions, and background information can be accessed and contributed to from anywhere.
- *Temporal distance* plays an important role in the EDC because design problems take place over periods of weeks and months, requiring that design rationale be captured in the reflection space to preserve the decision-making processes of others, and remind stakeholders of decisions they have made in the past.
- *Conceptual distance* is explored with a focus on communities of interest (which bring different communities of practice together) in which the individuals do not share a common work practice, but rather come together for the purpose of solving a particular problem.

Unique opportunities exist at the intersection of "going large" and "going small." *Caretta* [Sugimoto et al., 2004] is an extension of the EDC that integrates individual and social design activities [Fischer et al., 2005] by using wireless and mobile devices to bridge personal and collaborative work within and across different interaction spaces in face-to-face settings. Caretta provides users with personal spaces for individual reflections (based on PDAs), a shared space for group discussions (based on boards similar to the EDC), and intuitive transition methods between these spaces. Caretta users can discuss and negotiate with each other in the shared space by manipulating physical objects, each of which is enhanced by a radio frequency (RF) tag for rapid object recognition. An augmented reality technology for overlaying virtual graphics onto the shared space through a liquid crystal display (LCD) projector creates an immersive collaborative environment that enhances interactions and mutual awareness among users.

5.3 Going Everywhere

We explored a distributed intelligence environment for information sharing by building and testing a computing environment using wireless and mobile computing devices and physical objects with embedded RFID tags.

In the physical world, it is common practice to attach a piece of paper with notes on it (e.g., Post-It® Notes) to an object to associate information with it. A relatively new idea is to use machine-readable IDs of physical objects to allow various users to perform ID-based information access (i.e., to access information that is associated with the IDs) [Want et al., 1999].

The analogy between Post-It Notes and ID-based information access is appealing, but it can be taken only so far. A key reason the analogy breaks down is that pieces of digital information are more flexible than physically limiting pieces of paper. Digital information can represent dynamic media such as movies and animations; can be copied, transferred, and processed easily; can automatically trigger events; and in very large numbers can be associated with a physical object.

The *QueryLens* system [Konomi, 2002], which was implemented by using mobile computing devices and RFID tags, accumulates queries, connects them to a relevant physical object, allows users to share and modify them, and uses them to capture answers (see Figure 3). *QueryLens* extends ID-based information access to function in dynamic and social environments, where users can participate in the process of designing and extending the information space. Unlike conventional mobile information-sharing environments, *QueryLens* is based on a *socio-technical approach to empower users by facilitating them to engage in informed participation* rather than forcing them to be the users of existing information environments. Conventional location-based and ID-based learning applications could also be extended to support open evolvable information spaces for longitudinal learning processes and informed participation.

6 Reflections on Opportunities and Pitfalls

Our experiences with the specific application systems have shown that wireless and mobile technologies can create exciting opportunities for intelligence augmentation, social creativity, informed participation, and support of unique needs of users in achieving their tasks and engaging in personally meaningful activities. Wireless and mobile technologies, however, are not without potential pitfalls, including getting trapped in gift-wrapping and techno-determinism, a limited understanding of the roles of tools in distributed intelligence, the destruction of place, violations of privacy, and a limited understanding of the innovation potential.

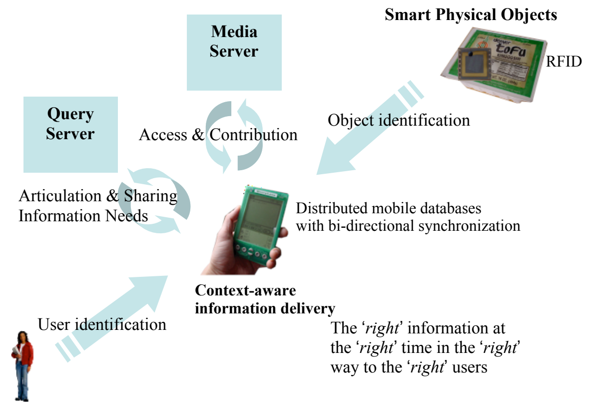

Figure 3: The *QueryLens* System

From Gift-Wrapping and Techno-Determinism to Co-Evolution. To exploit the full potential of wireless and mobile technologies in education, we need to transcend gift-wrapping approaches and techno-determinism. There is nothing wrong with gift-wrapping, but it is limited in scope and innovation. For example, teachers can "webify" a course by making teaching materials available on the Web rather than distributing them as paper copies. Simple push-button devices such as *clickers* [Dubson, 2003] can be used to precisely measure responses to a teacher's question rather than manually counting the raised hands of many students. These technologies may change the economics of teaching and learning; however, they contribute little to introducing fundamentally different approaches to learning [Fischer, 1998].

Roles of Tools. Distributed intelligence creates a framework to emphasize and promote *tools for living* versus *tools for learning* in education. Understanding the implications of this distinction is a critical problem for educational decisions. There are numerous activities that people cannot do without tools, so in these cases there is no choice but to rely on tools for living. Wireless and mobile technologies have the important potential to make tools available at all times and all places, thereby making the tools-for-living perspective more viable for numerous applications [Oppermann, 2005]. A lack of focus on tools for learning can lead to deskilling and learned helplessness because people becoming over-dependent on their tools. Our experiences with the *Mobility-for-All* project suggest the importance of understanding this distinction individually for users based on their unique capabilities.

Always On. Wireless and mobile technologies are making it possible to access digital information resources, use online services, and communicate with people anywhere at any time, creating a distributed intelligence environment across the boundaries of place and time. Breaking the conventional boundaries introduces the pitfalls of *destroying the notion of place and the time for reflection*. The *EDC* is designed to support the notion of a place in face-to-face collaboration settings [Olson & Olson, 2001].

Privacy. It is necessary to understand users and their tasks in order to provide *"the 'right' information, at the 'right' time, in the 'right' place, in the 'right' way, to the 'right' person"* in a distributed intelligence environment [Konomi, 2004]. Decontextualized information delivery such as Word's "Tip of the Day" could be avoided if the system understands users' preferences and their current tasks. However, the desire to know more about users and tasks may interfere with users' privacy needs. The *QueryLens* system captures users' context by using RFID, a controversial technology due to its privacy implications.

Privacy is an essential factor in intellectual processes and learning in a distributed intelligence environment: "*at the intellectual level, individuals need to process the information that is constantly bombarding them, information that cannot be processed while they are still 'on the go'*" [Westin, 1967].

Innovation. How innovative are our ideas about the use of wireless and mobile technologies in education? Our innovations should not be restricted to new technologies, but they should support the co-evolution of social practices, new media, and new learning organizations [Brown, 2003; Roschelle, 2003]. It is not technology per se that matters, but *technology-in-use*. To deeply understand the real impact of wireless and mobile technologies on education, we need to shift the discourse from a concern about who has access to new information technologies to who can use them in interesting ways for personally meaningful tasks [Barron, 2004].

7 Conclusion

The last decade has seen far-reaching changes in living, learning, working, and collaboration, fundamentally influenced by information and communication technologies, specifically the World Wide Web. Projecting ten years into the future [Roschelle et al., 2005], we may ask what the impact of wireless and mobile technologies will be. We should take up the challenge that the future is not "out there" to be discovered (like Columbus discovered America), but has to be invented and designed, and as wireless and mobile technologies become widely available, the WMTE community should be a major force in this challenge — not only to promote the technologies, but to make major contributions to fundamentally rethinking, reinventing, and redesigning the future of education.

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