ActiveCampus - Experiments in Community-Oriented Ubiquitous Computing*

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Abstract

The UCSD ActiveCampus project is an exploration of wireless location-aware computing in the university setting. ActiveClass supports classroom activities such as anonymous asking of questions, polling, and student feedback. ActiveCampus Explorer supports several location aware applications, including location-aware instant messaging and maps of the user's location annotated with dynamic hyperlinks of nearby buddies, digital graffiti, etc. This paper describes results on the use of these systems by several hundred students, drawing on observations, aggregate usage data, anecdotes, and the analytical perspective of Ecologies. Analysis exposes novel behaviors, the relevance of proximity in social computing, and a willingness to share location information with others.

Keywords: ubiquitous computing, mobile applications, wireless communications applications, education.

1 Introduction

The continuing proliferation of handheld computing devices holds out the promise for a new generation of computing applications that could enrich our experience of the world around us. Yet many issues must be overcome for this vision to be realized: What applications will enrich our lives? What kinds of interfaces will make them usable in dynamic, social settings? How should the devices themselves be designed? What kind of infrastructure can best support the development and delivery of application services?

The UCSD ActiveCampus Project has been investigating these questions in the university campus setting, using the activities of students and professors as our application driver. Demographic shifts are bringing more students to our campus. More are working and living off-campus, compromising the learning community that the campus setting is meant to nurture.

Sustaining dispersed communities through virtual spaces is well known [Rhe00]. Direct support of physical communities is seen in the discourse enabled by E-Graffiti [BG01, BG02] and GeoNotes [EPS+01], where users can leave their electronic thoughts in physical space for those who follow (See Section 2.2). These projects provide a compelling application and warn of the need for a large community and sufficient content to be successful.

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We began with the null hypothesis that recent proposals of applications employing context-aware ubiquitous computing, running on existing infrastructures and handheld devices—especially Personal Digital Assistants (PDAs)—could fulfill the promise. None of these are a given. The applications are novel and not well understood; the devices, although the best all-round platform available, are designed for mobile professionals maintaining calendars and contacts.

We first developed a context-aware application infrastructure and an array of application services [GBBT03], and then conducted extensive device deployments through coordinated student activities. We began with a simple application called ActiveClass, designed to encourage student participation in large classroom settings [RSTG03]. In Winter and Spring quarter 2002, we gave HP Jornada PocketPC PDAs with 802.11b wireless networking to 350 students enrolled in three classes, two sections of our second programming course (CSE 12), and one section of our third programming course (CSE 30). To the last class we also introduced the ActiveCampus Explorer application [GBBT03]. It is designed to help students and faculty take advantage of unseen opportunities for learning and interaction on the campus, such as nearby activities or meeting with a colleague. Lastly, in Fall 2002 we gave wireless HP Jornada PocketPC PDAs to the 300 freshmen entering UCSD's new residential college, Sixth College, and sponsored the Sixth College Explorientation, a three-day team challenge using the PDAs and ActiveCampus Explorer.

For sustainability, it was desirable to create "viral" technology, whose value would increase with the number of users, eventually becoming self-sustaining. For virality as well as equal access, we took a "lowest common denominator" technology approach, assuming that users would find greater value in more fellow users than richer applications.

We came to use an *ecological* approach [Hug71, Sta95] in order to put our experiences and experimental data in perspective, which effectively combines the viral and economic viewpoints into one analytical perspective. An ecological perspective denies the dichotimization of social and technical elements of a setting, putting all people, artifacts, and practices on an equal analytical footing, thus permitting us to see the cooperative and competitive forces of the setting operate across these elements.

The evidence thus far is that significant innovations and changes to hardware, software, physical infrastructure, as well as some teaching and learning practices, are required before the use of handhelds can support a diverse, widespread educational community in the way we envision. Yet, for focused activities of limited duration, success can be found.

The next section describes our applications, followed by a summary of our experimental results. We conclude with a discussion of their implications for research in handheld-based context-aware computing.

2 ActiveCampus Applications

To meet our goals of access and sustainability, we held to several 'design rules'. One, infrastructure and end-user technology would build on portable standards and impose minimal demands on the technology on which they were built. We gravitated to a client-server model, on the server side using a standard web server with MySQL and PHP to support applications. Two, the applications serve basic HTML, ensuring that virtually any networked device can render its content in a web browser. Optionally, a SOAP remote procedure call (RPC) interface supports client-side tasks such as detecting and reporting location. Three, computational demands on the client must be minimal, as community-oriented computing takes place in a milieu of activities.

In user interface design, the interface must minimize typing, as it is tedious and distracts users from the very environment we wish to highlight. Interfaces must be easy to grasp, even in a dynamic setting. Since early results with E-Graffiti [BG01, BG02] revealed the appropriation of graffiti for messaging, we decided to support multiple applications within our framework, with simple transitions between applications.

System scalability is important. Testing on our 1GHz server showed that it could handle 300 users. Everyone checking their buddy list at the same instant could increase load thirty-fold, however. Consequently, we put a rate-limiter into the system's automatic push mechanisms to gracefully degrade quality of service. On each interaction with the server, the client is told how long to wait before reloading a page or sending location data. Internal caching mechanisms avoid unnecessary requerying of the database [GBBT03].

The next two subsections describe our applications in some detail.

2.1 ActiveClass

Classrooms have evolved to accommodate a large number of people, employing stadium seating, microphones, and LCD projectors. These changes do not address the social dynamics of a large, diverse classroom of students. To fill this gap, we developed ActiveClass (available at http://activecampus.ucsd.edu), a simple client-server application for enhancing participation in the classroom setting via small mobile wireless devices such as PDAs. ActiveClass is intentionally minimal in both its function and requirements for integration into classroom practice. The former permits students to

Figure 1: Question list sorted by question vote count. A student votes on a question by clicking its vote count (at left), or answers a question by clicking the count under the "A" column.

Figure 2: The Map and and Buddies pages of Active-Campus, as shown on an HP 548 Jornada for a user "Sarah". Map shows an outdoor or indoor map of the user's vicinity, with buddies, sites and activities overlaid as links at their location. Buddies shows colleagues and their locations, organized by their proximity. Icons to the left of a buddy's name show the buddy on the map, begin a message to the buddy, and look at graffiti tagged on the buddy. Separate pages show lists of sites, graffiti, and buddies, and perform operations on them.

use low-cost mobile devices, the latter eases adoption by professors.

The idea behind ActiveClass is simple: using personal, mobile wireless computing devices, students can anonymously ask text questions, answer polls, and give the professor feedback on the class. The students and professor see these lists of questions, polls, etc. Students can vote on asked questions, encouraging the professor to give them precedence. The modality is a silent, aggregated, broadcast conversation. The identity of the student asking a question is fully hidden from other students, and hidden from the professor unless he or she takes deliberate action.

A Class with Sim. Sim is a student in Professor G's class, the second programming course for CS majors. The topic today is hashtables. "Why doesn't the program need to search the whole table?" she thinks. Because nobody else seems to be lost, she doesn't want to raise her hand. She decides to ask her question through Active-Class. With her stylus, she types it in on the keyboard that pops up on the PDA's display. The PDA's word-completion suggestions reduce the effort of typing in long words. Soon she notices that many students have voted for it (by clicking on its vote count) and it rises to the top of the list (Figure 1).

Professor G. looks at the top question and realizes several students have missed a key concept. He uses a recent homework problem to illustrate how the relationship between key and placement limits the search.

Sim is relieved to have had her question answered. She goes to the ratings page, gives the teacher a 9, and clicks Just Right for the speed of the lecture.

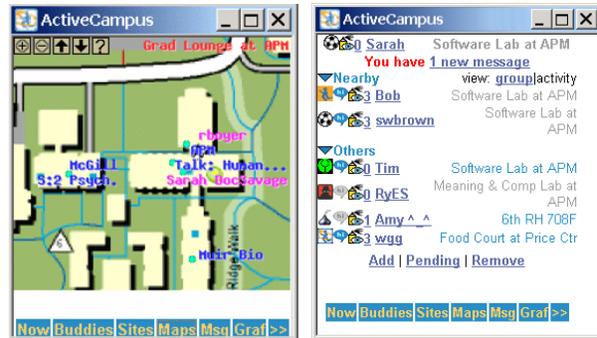Professor G. saves the day's questions. Seeing the ex-

cellent hashtable question again, he goes to its Spy page, which lists Sim as the author, as well as the answers that others have entered for it. He notes Sim as a potential tutor for next term.

2.2 ActiveCampus Explorer

Our approach to supporting denizens who are moving about their community is a variant on a familiar theme [MM99, OS00, LKAA96, PBC+01]: if each person on campus carried a mobile, wirelessly connected device, then it could be used as a kind of "x-ray glasses" onto their immediate vicinity that would let them see through crowds and undistinguished buildings to reveal nearby friends, potential colleagues, departments, labs, and interesting events. Opportunities once unnoticed are now apparent, creating serendipitous learning opportunities.

A simple realization of this concept, appropriate for a handheld like a PDA, is shown in Figure 2. In the left screenshot, the large area is a map of a person's immediate vicinity. Overlaid are labels showing the location of nearby departments and friends. The labels are URLs that can be clicked to bring up a web page. A nearby colleague, formerly no more available for lunch than a hundred others, is seen to be nearby and can be instantly messaged or found on foot. Any place or entity can be tagged with digital graffiti, supporting contextual, asynchronous discourse.

ActiveCampus currently detects location through the PDA's report of currently sensed 802.11b access points [BBG04]. Their reported signal strengths and known locations are used to infer the user's location by a

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least-squares fit. Also, users' point-and-click corrections of location on the map are saved with these reports, refining future location inferences.

A Day with Sarah. Sarah walks out of her introductory electrical engineering lecture, wondering where was the engineering her Dad had told her about—building things that improved people's lives? Glancing at her PDA, ActiveCampus shows a map of her vicinity, and she sees a link to a talk with "human" in the title (Figure 2, left). Clicking through, she sees there's a talk starting in the engineering building on the human-machine interface. She decides to go.

After the talk Sarah heads to the food court for some lunch, hoping to tell to someone about the talk. Looking down at her PDA, she sees that her "buddy" Brad is nearby and active (both location and message icons highlighted in blue), and sends him a "Wanna go eat?". Brad notices the "dome" on his PDA flashing,[1] and flips it open to see that Sarah has sent him a message and is nearby. Now both looking for each other, they see each other through the lines of people and sit down to talk about their day.

Later, Sarah notices that the tree outside the library is not dead, as she'd thought—it's made out of metal and talking quietly. Flipping open her PDA, she clicks over to the digital graffiti page of ActiveCampus. There's a list of graffiti that's been "tagged" in the area, including a "living dead tree" link near the top. Clicking on different parts of the tree leads to different parts of an interactive artwork. She clicks on the spray can to the left of the graffiti's subject line, and is taken to a page where she "tags" the interactive tree with "Thanks tree!", to be seen by others who view the living dead tree through ActiveCampus.

3 Experiments and Experience

3.1 ActiveClass Experience

The ActiveCampus PDAs were introduced into an environment possessing considerable social, physical, and technological complexity. Consequently we separate two aspects within the classroom ecology, termed the political (i.e., the relations between professor and students) and physical (the desks, artifacts, and layout of the classroom). These aspects can be linked through the concept of Brand's shearing layers [Bra95, Ch. 2]. The differing rates of change of these two layers/aspects has qualitatively different effects on classroom practice.

The Political Aspect. For our study, two staff lecturers volunteered, both highly motivated and sympathetic to the students. The first lecturer cited many concerns about ActiveClass.

One was ActiveClass's complete anonymity. Consequently, we provided a feature that let him "inspect" a question for its author (providing a thin veil of anonymity), while maintaining complete anonymity among the students.

Two was that ActiveClass would be difficult to integrate into his routine, another thing for him to manage during the class. We encouraged using a Teaching Assistant (TA) to monitor the session for appropriate use and the like. Then he could ignore ActiveClass until his usual breaks for questions.

He also took to calling his laptop "the virtual student". This metaphor had two benefits. For him, it meant that his laptop was just one more student asking questions. He would usually refer to the virtual student only after taking questions from students raising their hands, indicating a preference that students participate verbally. For the students, it meant that apparently negative reactions to a question from ActiveClass were absorbed by the virtual student.

A tendency among the students and TAs was to use the question and answer features as affordances for communication. First, we observed students sometimes answered questions by using the Ask Question feature. This led us to add the Answer Question feature (and later, 1-click answer-scoring that TAs used). Once in place, students sometimes used it to thank those providing helpful answers. The TA monitoring the session would sometimes use it to answer questions that were off topic. The professor, too, used the ActiveClass session to carry questions between class sessions or out to the class's discussion board. Here, ActiveClass was impacting the boundaries of the ecology.

A few data points convey ActiveClass's role in the classroom. About a third (1/3) of students provided some kind of input (question, vote, etc.) to ActiveClass on a regular basis. In CSE 12, the average number of questions asked per class session was 8, and on average 40 votes were cast per class session. (These numbers were slightly lower in CSE 30, where the lecturer's style was more interactive.) Once the answer feature was introduced, essentially every question that was not directed specifically to the lecturer was answered by another student, with a maximum of 8 different answers for a question.

Although the level of participation seems low, we note that the lecturer took verbal questions in preference to ActiveClass questions, and he carried over good questions to his second section. The next subsection on the physical aspect sheds additional light on the level of usage.

By our judgment, and the lecturer's, the level of the questions was quite high and qualitatively different than seen before. After the first use of ActiveClass in CSE 12 (third week into the term), he said:

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[1]The flashing dome feature has been prototyped but not deployed. ActiveCampus also uses the second line of each page to convey events like a message arrival.

The most surprising aspect from today is seeing students ask questions that I don't recall ever being asked in prior versions of CSE 12. A few of these questions were especially insightful. I was very pleased to answer these questions that hadn't occurred to me, and the result is that all students were able to benefit.

His response also hightlights that even students who don't use ActiveClass directly are potential beneficiaries.

Putting these observations together with our detailed session data from ActiveClass, we found that the anonymous materialization of questions in a public space affected the classroom ecology in several ways. It gave the students the ability to ask questions without revealing their identity to peers, resulting in a broader range of questions. This in turn gave the lecturer the ability to pick questions to answer (not people to ask questions), thus filtering the spoken discourse. Yet, the lecturer did not choose these questions in a vacuum—student voting influenced the lecturer's filtering. Finally, ActiveClass gave TAs and students the ability to answer questions, often questions not answered by the professor.

Each "feature" of ActiveClass questions gave something *different* of value to two or more parties. Although students may have been motivated to ask questions in ActiveClass by a certain level of anonymity, the lecturer in contrast liked this feature for the ability to pick questions (rather than people who ask questions). Thus, we find that ActiveClass improved the fitness of question-asking by moving the focus from the *people* who asked the questions to the *questions* themselves. This level of fitness is not perfect, of course. For example, some experiences with ActiveClass suggest that incomplete anonymity may inhibit some students.

The last essential element was the lecturer's tolerance for "unapproved" uses of the PDA's, such as instant messaging and playing games. Both lecturers felt responsible for creating an environment that held the students' attention, and thus tolerated such activities as long as they didn't distract other students. The PDA's small display and quiet pen-based input were beneficial in this regard.

It is notable that this group practice was not born whole, but emerged through "experiments" by the lecturers, students, TAs, and researchers. Like Brand's shearing layers, variations on practice could be achieved at differing rates depending on the medium. By exploiting affordances (e.g., answering a question with the asking feature), students could attempt and learn from innovation with a minute's effort, whereas the materialization of practices in ActiveClass's implementation took a few days. Yet, changing the classroom itself can take years. This leads us to...

The Physical Aspect. Students must use their PDAs within the constraints of the physical setting of the classroom, with numerous other artifacts. Our students' desks were designed to barely accommodate standard-sized notebook paper, and are slightly sloped towards the student.

Like paper, use of a PDA requires line-of-sight access for reading and interacting, plus it has a limited viewing angle. The PDA's small screen, crammed with clickable features requires some precision when using the pen.

The students incorporated various PDA "postures" into their practices, most to keep their PDAs nearby while maintaining the primality of paper for note taking. A popular tactic was to place the device on top of the paper on the desk. The PDA of course partially occludes the page, necessitating that it be frequently moved. Students would also use a leg as a second platform or their free hand to hold the PDA in the air.

For many students, note taking forms a bridge between the lecture and out-of-class practice. Because ActiveClass is physically detached from students' notebooks and contains content not found there, it was not deeply connected to note-taking practice. Students asked "How can I use this to study?" In response, we added an archiving feature to ActiveClass that allows users to view previous sessions.

Students also had to accommodate the technological faults of ActiveClass, this new generation of networked PDAs, and the campus's wireless network. Ultimately, many students, finding the management of the additional objects inconvenient, chose not to use their PDAs.

In assessing the impact of ActiveClass, a natural question is whether it measurably aids learning. We do know that it was found beneficial enough to sustain use. The lecturers professed that they would use ActiveClass again, and one-third of students voluntarily used ActiveClass on a regular basis. This initial experiment cannot answer the learning question, however. First, as a case study, we did not control for selection bias. Second, at the inception of this study, we did not know by what mechanisms ActiveClass might aid learning. We can now hypothesize that it concerns the broadening of discourse, and we can look for changes in learning outcomes at the extremes. For example, are more students pursuing independent research later in their studies, or are fewer students dropping classes? Such learning outcomes would not necessarily appear in measures such as test scores.

3.2 ActiveCampus Explorer

The results from ActiveCampus Explorer have a significantly different character than the ActiveClass results, shedding light on the importance of the social, physical, and technical setting to the use of handhelds. Because their use occurs at unpredictable and inaccessible times

and places, we currently lack detailed observation of practices with ActiveCampus Explorer. In lieu, we have our own experience and aggregate data collected by the ActiveCampus system.

3.2.1 Experience.

Our own experience with ActiveCampus Explorer has been quite positive. However, these results were achieved in part by refusing to be deterred by physical and technical obstacles. Here are a few example scenarios:

- Ben drops by Bill's office, but he's not there. Ben checks his PDA and sees that Bill is at the cafeteria across the quad. Ben heads over to the cafeteria and joins Bill and Jens for lunch.

- Bill is late for a meeting, but has to pick up some lunch first. The group waiting for him sees that he's at the food court, and concludes that he'll be arriving shortly.

- Bob is waiting in the lab for Bill to get in. When Bill pops up on his buddy list at the location "Griswold's at APM", he heads over to Bill's office.

- Andrew urgently needs to discuss some class project details with Bill. Andrew checks his PDA and sees Bill in the Cove Room at the Price Center foodcourt, and runs over for a short conversation.

- Bill is waiting for a colleague to join him at the Art of Espresso cafe. Checking the graffiti on the cafe he sees "AoE has the best croissants on campus." Bill makes a note to try them.

As with ActiveClass, there are considerable barriers to the successful use of ActiveCampus Explorer on wireless PDAs, but the causes are somewhat different. Although use is less politically charged, there are numerous new challenges, driven by the less structured, more dynamic environment in which ActiveCampus Explorer is expected to be used.

PDA Design. Wireless PDAs have limited battery life, typically under 4 hours with wireless connectivity. A student could be away from a reliable power source for 16 hours. Nor is it easy to configure the PDAs to cyclically wake and sleep to conserve power. Often a running application or the networking itself will keep the PDA awake. Worse, PDAs predominantly have dynamic RAM storage, so if the main and backup batteries die, the PDA's settings must be restored. A restore requires time and some savvy. The wireless networking can hang permanently if the PDA hits a dead zone while being moved between hotspots, requiring a reset to restore connectivity. Using the stylus to enter (non-standard) text messages is tedious.

Software Infrastructure. Although the use of HTML achieves instant ubiquity, a significant loss is true push-interactivity from the server. We use periodic refreshing to minimize this problem, but issuing alarms and the like is not possible. Consequently, users must "keep an eye" on the PDA for the arrival of ActiveCampus Explorer messages, notice interesting graffiti, etc., as one moves about.

Graffiti Issues. Digital graffiti did not appear on maps or notify taggers of activity on their graffiti, making them less visible than sites and users. Also, there is no provision for deleting or hiding unwanted graffiti, creating clutter.

Physical Constraints. With a PDA and software infrastructure that makes it difficult to reliably wake a PDA periodically and push alarms to a user, it is best to keep the PDA on and within view, or at least handy. Most men have good solutions in loose shirt and pant pockets, but women's clothing typically lacks these affordances. Also, placing a PDA on a flat table often leaves it at an angle where it is hard to read the screen. Indeed, we have seen people propping up their PDAs with the edge of a book or a pencil. We are now experimenting with alternative solutions to the physical placement problem, such as attaching a PDA to a clipboard.

3.2.2 Aggregate Usage Characteristics

Since we had research questions concerning the requirements for self-sustaining behavior and other emergent properties, we performed aggregated, anonymized analyses of our server data from ActiveCampus Explorer's "launches" in April 2002 through May 2003. The first was in conjunction with one of the ActiveClass groups, the second for the Sixth College Explorientation. The launches were meant to create a structured, supportive context for students to use ActiveCampus Explorer. These events were useful both for generating data quickly in a semi-controlled setting, as well as for providing the opportunity for bootstrapping a virtually mediated community, or at least getting a sense for how one might behave. In both launch sessions, the students were encouraged to try each feature.

Measures of use based on the number of transactions gave excessive weight to a few heavy users. We instead examined how many distinct people were creating content for each feature. The top chart in Figure 3 shows the number of distinct individuals who created each type of content during each month. The peaks correspond to the two launches. Generally, use decays at an exponential rate, a factor of two, over a month to month basis, until it stabilizes around 25 users. About a third of these are members of the ActiveCampus project. This disappointing outcome can be attributed to the ecological deterrents cited above.
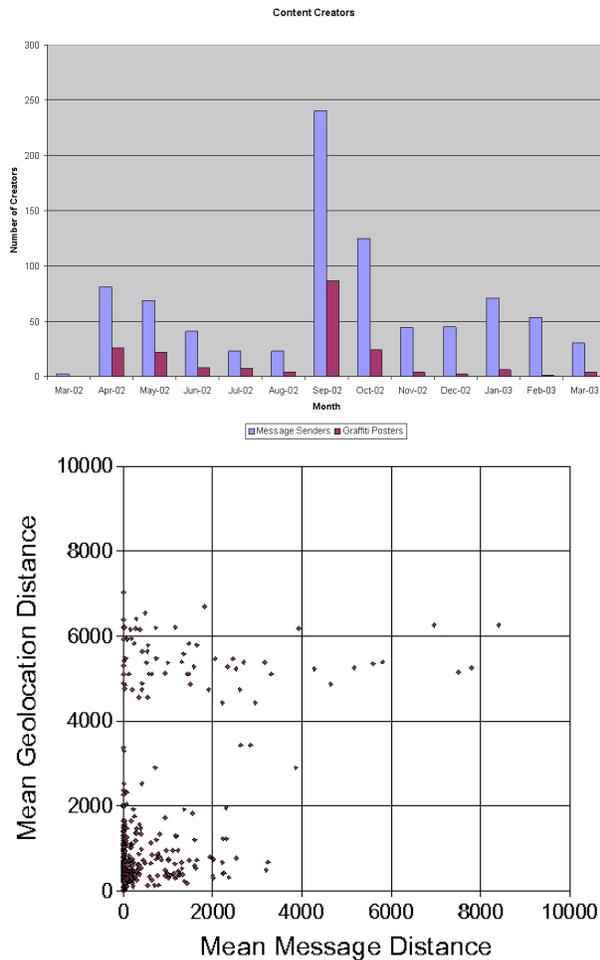
Figure 3: Messaging and graffiti creation statistics.

Since one of the underlying principles of ActiveCampus is that location matters, we analyzed message sender and receiver locations. This analysis was limited to the 1597 messages for which both the sending and receiving PDA had been located by the automatic geolocation system within the previous 100 seconds. There are numerous reasons why a user might not be currently geolocating, including use of a non-located computer or the user's choice to to hide location.

Next, we compared each sender-receiver pair's average distance at the time of messaging to their average distance in general. The lower chart Figure 3 shows this relationship. For 473 out of 539 pairs the distance when messaging was less than the average distance. For 311 pairs the average messaging distance was less than 50 feet. This tendency held up when members of the project were excluded from the analysis, as well as data from the Explorientation.

In short, relative location as a context seems to matter in community-oriented computing. Perhaps ActiveCampus Explorer's presentation of nearest buddies at the top of the list highlighted their proximity. At the shortest distances, the pairs may have physically seen each other in the same room (using IM as a back channel) or knew they should be in class together.

Finally, we examined privacy issues. Just 1% of users changed their default privacy settings to hide location from buddies, and 8.2% exposed their presence and location to non-buddies (0.3% more exposed just presence). In short, users seem unconcerned about location privacy with friends. A modest percentage will even trouble themselves to share location with non-buddies, perhaps as a way to meet people.

4   Conclusion

Even at this early stage in the development of wireless handheld computers and their applications, our experience at UC San Diego reveals considerable promise. With the structure provided by the classroom setting, a simple application like ActiveClass, by anonymously materializing questions in a public space, can create new modalities for participation in the classroom, in our case broadening discourse. A location-aware computing application like ActiveCampus Explorer, with its many services, shows potential to create impromptu opportunities for users.

Yet, considerable progress is needed. Mundane issues such as battery life, data loss, and connectivity make these applications difficult to use. These issues are certain to be resolved soon, but illustrate the sensitivity of technical innovation to material circumstances. The office and business travel environments in which PDAs have flourished do not present these challenges to the same extent.

The one-way nature of existing standardized communication technologies also presents challenges to ubiquitous context-aware computing. Standard SOAP RPC does not fix this problem, as it retains HTTP's 'pull' semantics. We are now developing a native ActiveCampus Explorer client that uses off-the-shelf XML-based instant-messaging frameworks for managing a 'push' connection to the client that can negotiate firewalls and restore a lost connection. The native client can also provide better client-side animations and use of sound to direct the user's attention.

The social barriers to handheld computing are perhaps the most significant. As computing moves into public spaces, the issues of regulating access, sharing resources, and acceptable use remain to be resolved. ActiveClass puts the power of negotiation into the application itself. It's unclear if these ideas can be extended to ActiveCampus Explorer. Although ActiveCampus Explorer's buddy visibility policies have some of that character, it is difficult

to tell at this time what effect they have had.

The fact that students are willing to share location with buddies and even non-buddies suggests promise for location-aware social computing. Also, the fact that students are more likely to message each other when they are closer than average is a tantalizing observation, suggesting that relative location is a relevant context factor in community-oriented computing.

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