Title
ActiveCampus - Experiments in Community-Oriented Ubiquitous Computing

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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, on the premise that the learning activities of busy students and professors on a large university campus could provide a meaningful application driver for our research in handheld computing. A university is an institution for learning, through both research and teaching. It gathers the learners into a physically proximate community, so that learning can be enhanced by their interactions. Its campus should nurture that learning community by providing an environment in which its activities and interactions can flourish. As demographic shifts bring more students to our campus while also leading them to pay for their own way, more are working and living off-campus, compromising the focus that the campus setting is supposed to create while also making the campus more anonymous.

To gain insight on the above questions in our setting, we began with the null hypothesis that recent application proposals employing context-aware ubiquitous computing, running on existing infrastructures and handheld devices—especially PDAs—hold promise. 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. Supporting these communities on existing infrastructures and PDAs (in this case HP Jornada PocketPCs) is not a given. The applications are novel and not well understood, and the devices themselves are designed for mobile professionals maintaining calendars and contacts.

We developed a context-aware application software infrastructure and an array of application services [GBB+02, RSTG03, GBBT03]. Our approach is a variant on a familiar theme[MM99, NIH01, OS00, LKAA96, PBC+01, DCME01]: if you and every person on campus carried a mobile, wirelessly connected device, then it could be used as a kind of “x-ray glasses” onto your immediate vicinity that would let you see through the crowds and undistinguished buildings to reveal nearby friends, potential colleagues, departments, labs, and interesting events. By making the clutter transparent and highlighting otherwise invisible things, once-unnoticed opportunities are now apparent, creating serendipitous opportunities for learning.

In concert with these development efforts we have con-

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ducted deep device deployments through coordinated student activities. We began with a simple application called ActiveClass, designed to encourage student participation in large classroom settings. In Winter and Spring quarter 2002, we gave 802.11b wireless HP Jornada PocketPC PDAs to students in three introductory programming classes, 350 students in all. To the last of these classes, we also introduced an application called ActiveCampus Explorer. It is designed to help students and faculty take advantage of unseen opportunities for learning and social interaction on the campus, such as nearby activities or meeting up with a colleague. Lastly, in Fall 2002 we gave 802.11b wireless HP Jornada PocketPC PDA's 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.

In our design and deployments, we paid special attention to issues of access. It was apparent that affordability was critical. Both universities and student populations are often strapped for resources. From an ethical perspective, it was also important that the technology was inclusive of the entire student body. From a "viral" perspective, it was desirable to create technology whose value would increase with the number of users, so that above a certain level, usage could become self-sustaining. In general, we took a "lowest common denominator" approach, assuming that there was greater value in having more users with simple applications rather than having fewer users with richer applications.

In reflecting on our experiences and experimental data, we came to use an *ecological* approach [Hug71, Sta95, Fuj95] to putting our experimental data in perspective, effectively combining the economic and viral perspectives into a single coherent analytical perspective. At the beginning of our investigations of ActiveClass use, much of our analytic focus was directed towards the technical details of the application and the personal experiences of individuals who used or did not use it. However, we soon found that this narrow focus did little to help us explain the practices that actually emerged within the classroom and the extent to which students participated in them.

A primary feature of the ecological perspective is that it puts all participants and artifacts in the same global analytical perspective. They can be seen as part of an overall system, none in the center, thus throwing the forces impacting their activities into relief, regardless of their source (e.g., political versus technical). Three features of the ecological notion were particularly helpful in understanding the complex classroom setting, and motivate its use beyond the classroom. First, thinking of the classroom as an ecology reminded us of the complexly interwoven physical, conceptual, social, and technical aspects that formed the classroom experience. Second, an ecological perspective redirected us to examine such seemingly mundane things as the physical layout of the classroom, the shape of student desks, and the many other artifacts and relationships that informed this space. Third, we were led to examine activities beyond the classroom, as the peripheries of any ecology may be disrupted by external forces, effectively blurring its boundaries.

From the ecological perspective, the evidence thus far is that significant innovations and changes to hardware, software, physical infrastructure, and even student practices are required before the use of handhelds can support a diverse, widespread educational community in the way we envision. Yet, for focussed activities of limited duration, or for those who are determined, considerable success can be found. We also find surprising evidence that location may play a role in the usefulness of handheld computing.

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

2 ActiveCampus Applications

To meet our goals of access and sustainability, we developed several 'design rules' in the development of our two applications, ActiveClass and ActiveCampus Explorer. One, both infrastructure and end-user technology would build on standards, be widely portable, and impose minimal demands on the technology it was built on. For example, on the server side, we use a standard web server with MySQL and PHP to support applications. This infrastructure can run on almost any machine an institution possesses. Two, the applications serve basic HTML, ensuring that virtually any networked device can render its content in a web browser. A SOAP RPC interface is available for supporting client-side tasks such as detecting location; making this optional limits exclusion. Three, computational demands on the client must be minimal, as community-oriented computing takes place in a milieu of other activities, and cannot dominate the device or excessively drain battery power.

We also developed a few simple application interface design rules. For example, interfaces must virtually eliminate typing, as not only is typing difficult and error prone, but it distracts the user from paying attention to the very environment with which we wish to reengage them. Likewise, the interfaces must be easy to grasp, even in a dynamic setting. In light of the early results with E-Graffiti [BG01, BG02], in which students used E-graffiti for messaging, we also hewed to the idea of supporting multiple applications and application extensibility within our framework, with simple transitions between applications.

The next two subsections describe our two applications in some detail. The subsequent section examines the results from deploying these applications.

2.1 ActiveClass

University classrooms, like other parts of the educational infrastructure, 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 Personal Digital Assistants (PDAs). ActiveClass is intentionally minimal in both its function and requirements for integration into classroom practice. The former permits students to use low-cost mobile devices, the latter eases adoption by the institution and professors. The basic idea behind ActiveClass is simple: using personal, mobile wireless computing devices, students can anonymously ask questions, answer polls, and give the professor feedback on the class. Every student and the professor see these lists of questions, poll results, etc. Furthermore, students can vote on previously asked questions. This raises their ranking in the display, encouraging the professor to give those questions precedence. The modality is a silent, aggregated broadcast conversation.

Scenario. By way of a scenario, we introduce ActiveClass and the modes of interaction we found it to support in our experiments. Although this scenario was constructed for illustrative purposes, all the examples here are based on actual data and experiences during the experiment. We refer to ActiveClass's users as *admins* and *users*. An admin might be the professor, one of his or her teaching assistants (TA's), or a designated student. Users are students. ActiveClass being a web application, we often refer to its features as *pages*.

Sim walks into CSE 12 a few minutes before class is to start, pulls out her wireless PDA, logs in to the ActiveClass server, and chooses the CSE 12 session. The class's Information page comes up with notes from the last lecture and links to some ancillary material.

At about the same time Professor G. enters the room, pulls out his overhead slides and boots his laptop. He logs into ActiveClass and navigates to the admin's Questions page, which summarizes the questions from the class session and refreshes every 30 seconds. Now if he wants to take questions during class, he can quickly have a look at his laptop to see what's going on. One of his TA's has also logged in as an admin and will actively monitor the session.

Professor G. begins his lecture, explaining how hashtables are an efficient way to search. He stops occasionally to make sure everybody understands, although he gets little response.

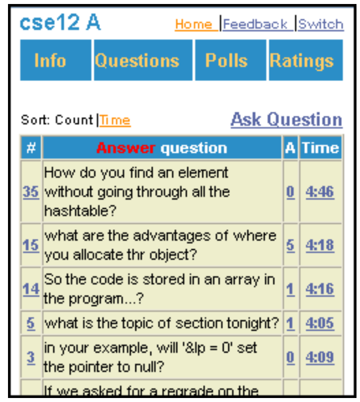

Figure 1: Question table sorted by question vote count.

Sim's lost. She doesn't understand why the program doesn't need to search the whole table for an element. Because nobody else seems to be lost, she doesn't want to raise her hand. Maybe Prof. G. already answered her question and she missed it while taking notes. Knowing that the midterm is coming soon, she decides she'd better ask her question through ActiveClass. Soon after asking the question she notices that many students are voting for it, and it rises to the top of the list (Figure 1).

Professor G. knows that at least a few students must be lost. He says, "Let's see if the virtual student has any questions," switching his attention from his overheads to ActiveClass. Looking at the top-ranked question, he realizes they've missed a key concept. He draws on the students' recent homework experience with sorting to convey how keys relate to the placement of elements, and how that can help find an element quickly. He then reviews how hashing achieves the same goal without the cost of sorting. Students start raising their hands with follow-up questions. As the discussion concludes, Professor G. hides the question to reduce clutter in the view.

Sim is relieved to have had her question answered. Glad that the teacher took extra time to make things clear, she goes to the ratings page and gives the teacher a 9 and clicks Just Right for the speed of the lecture.

She returns to the question page, this time sorting the questions in chronological order with the newest questions at the top of the page. She notices that the TA monitoring the session answered a question about the due date of homework 4.

Now that class is over, Professor G. uses the Save to Warehouse feature on the Session page to capture today's questions. Thinking that one question was especially good, he goes to the Spy page. It lists all the questions and answers that students have entered. He clicks on the

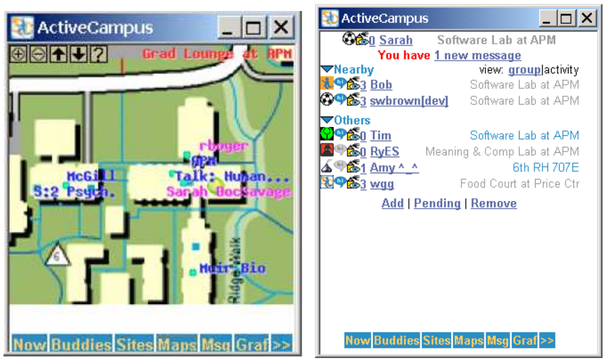

Figure 2: The Map and Buddies pages of ActiveCampus, as shown on an HP 548 Jornada. Map shows an outdoor or indoor map of the user's vicinity, with buddies, sites and activities overlaid as links at their location. Buddies shows colleagues and their locations, organized by their proximity. Icons to the 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, reached by the navigation bar or clicking embedded links, show lists of sites, graffiti, and buddies, and performing operations on them.

question to see who asked it. He goes over to his TA who has been monitoring the session, and asks him to point out Sim. As the TA nods in the direction of Sim, he says that she's always working hard in the computer lab. Professor G. makes a note to ask her to tutor for him next quarter.

2.2 ActiveCampus Explorer

A simple realization of the "x-ray glasses" concept outlined in the introduction, appropriate for a handheld like a PDA, is shown in Figure 2. The large area is a map of a person's immediate vicinity, as detected through some geolocation method. Overlaid are links showing the location of nearby departments and friends. Department links and the like can be followed to bring up a web page. A nearby colleague, formerly no more available for lunch than a hundred others, is seen to be in the vicinity and can be instantly messaged or found on foot. Any place or entity can be tagged with digital graffiti, supporting contextual, asynchronous discourse.

A Day with Sarah. Sarah, a UCSD computer engineering sophomore who transferred from Mesa Community College last quarter, walks out of her morning Engineering 53 lecture, introduction to electrical engineering. This isn't what I signed up for, she's thinking, wondering where was the engineering her Dad had told her about—building things that improved people's lives? Flipping open 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).[1] Clicking through, she sees there's a talk just starting in the engineering building on the human-machine interface. Curious, she decides to go. Although the talk gets technical quickly, the introduction has shown her a link between people and computer engineering.

Figure 3: The Messages and Graffiti pages of ActiveCampus.

Realizing she's hungry, Sarah heads to the Price Center for some lunch. Her usual table of friends is probably gone by now. Really wanting to talk to someone about adjusting to UCSD and her major, she checks ActiveCampus (Figure 2, right) and sees that her "buddy" Brad is nearby and active (both location and message icon highlighted in blue), clicks on him and sends him a "Wanna go eat?" with a couple of clicks (Figure 3). Brad notices the "dome" on his PDA flashing,[2] 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.

After lunch, Sarah decides to go to the library to get a head start on her Engineering 53 homework. Later, leaving the library, she notices that the tree outside the library is not dead, as she'd thought—it's made out of metal and talking quietly. That's so weird. Flipping open her PDA, she clicks over to the digital graffiti page of ActiveCampus, since a friend told her there was lots of arts stuff in there (by default graffiti is not shown on the map since it can clutter). There is a list of graffiti that's been "tagged" in the area, including a "living dead tree" link near the top (Figure 3). Clicking on different parts of the tree leads to different parts of an interactive artwork. Clicking on the tree's roots leads to a story about the tree, pointing her to other talking trees on campus, and gives the low-down on UCSD's Stuart art collection. Now she begins to understand all the weird stuff she'd been seeing on cam-

[1] ActiveCampus uses the PDA's report of all sensed 802.11b access points and their relative signal strengths to infer a location [GBB+02].

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

pus! Clicking on the spray can to the left of the graffiti's subject line, she is taken to a page where she "tags" the interactive tree with a "Thanks tree!" note to be seen by others who view the living dead tree via ActiveCampus. Walking off, she thinks, huh, I wonder if there is a role for art in engineering? She'd have to ask Mark about that.

3 Experiments and Experience

3.1 ActiveClass Experience

The ActiveCampus PDAs were introduced into a space possessing considerable social, physical, and technological complexity. Students using ActiveClass integrated it into this environment by adopting work practices that allowed their PDAs to work in concert with the physical setting of the class, the personal artifacts that were already included in students' class-going regime, and the technical challenges of managing computer systems.

In the next two subsections, we address two aspects within the classroom ecology. These are what we have termed the political aspects (i.e the relations between professor and students) and the physical aspects (the desks, artifacts, and layout of the classroom.) These two aspects can be likened to the different layers of Brand's description of how buildings learn [Bra95, Ch. 2]. Due to the differing rates of change of each aspect, they have qualitatively different effects on classroom practice.

The Political Aspect. Before the study began, Professor G. cited many concerns about ActiveClass. One was the broad-brush anonymity of the system. We compromised, giving him 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, he was concerned that ActiveClass would be difficult to integrate into his routine, as it would be yet another thing for him to manage during the class. However, by using a TA to monitor the session for appropriate use and the like, he was free to ignore ActiveClass until his usual breaks for questions. During these breaks, he took to calling his laptop "the virtual student". This metaphor for his ActiveClass session had two benefits. For him, it meant that his laptop was just one more student asking questions. He would usually refer to ActiveClass only after taking direct questions from students raising their hands, clearly indicating that he preferred that students participate verbally. For the students, it meant that any apparent negative reaction to a question from ActiveClass would be absorbed by the virtual student, and no aspersions would be cast on the students. Taken together, the metaphor indicates the professor intended to construct as positive an atmosphere as possible for active participation.

A few other behaviors point to the possible benefits of ActiveClass. More than once the professor used ActiveClass to carry classroom activity beyond the bounds of the 80 minute lecture. He did three things. One, he carried particularly good questions from his first section to his second section of the class. Two, he carried unanswered questions from the end of one class meeting to the beginning of the next one. Three, he moved a particularly rich question offline into the discussion forum; that is, the professor used the saved state of ActiveClass as a memory aid between the class time and the time he got around to moving the question to the forum. In short, ActiveClass was impacting the boundaries of the ecology.

An interesting tendency among the students and the TA's was to use both the question and answer features as affordances for communication. Indeed, we added the Answer Question feature because we observed students sometimes answered questions by using the Ask Question feature. Once the Answer Question feature was added, students sometimes used it to thank those who provided good answers. Also, the TA monitoring the session would sometimes use it to answer questions that were off topic, thus helping a student while keeping the professor and the rest of the class on topic.

A few data points give a feel for ActiveClass's role in the classroom. After the novelty of ActiveClass wore off, about a third 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 professor's lecture style was more interactive. Once the answer feature was introduced, essentially every question that was not directed specifically at the professor was answered by another student, with a maximum of 8 different answers for a question.

Although the level of participation may seem low, it must be remembered that the professor carried over good questions to his second section, reducing the need for entering additional questions in the second class. Also, by our judgment—and that of the professor—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:

> *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 points to the fact 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 ActiveClass affected the ecology of the classroom setting in several distinct ways. To start, it gave the students the ability to ask questions without revealing their identity, thus resulting in a broader range of questions. This in turn gave the professor the ability to pick questions to answer (not people to ask questions), thus filtering the discourse in the speaking modality. Yet, the professor did not choose these questions in a vacuum; ActiveClass gave the students the ability to vote on questions, providing information to the professor that could influence the filtering of the spoken discourse. It gave the teaching assistants (and the students, too) the ability to answer questions within ActiveClass, often questions that were filtered out of the spoken modality.

It is notable that each "feature" of ActiveClass gave something *different* of value to two or more parties. For example, although students may have been motivated to ask questions in ActiveClass by a certain level of anonymity, the professor in contrast liked this feature for the ability to pick and choose 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 is the fundamental conundrum for both student and professor in the question-asking act: the student raises his or her hand (or not), unsure whether the professor will embrace the question; likewise, the professor calls (or does not call) on the student, unsure whether the student's question will be worth the class's time. With ActiveClass, the question is revealed—and even voted on—without the student being called on, thus saving the student and the professor possible discomfort. Questions that the professor will not or cannot take can be answered within ActiveClass itself by a TA. In essence, the fitness gradient for a question is dramatically reshaped from a very steep curve based on guesses by both student and professor to a shallow curve based on the question itself.

It is notable that this practice was not born whole, but emerged through "experiments" on behalf of the professors, students, TA's, and researchers. Like Brand's shearing layers [Bra95, Ch. 2], 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 could take a day or more. This is beneficial because practices are probably best not materialized for all to use unless the low-cost innovations show some benefits on their own.

Finally, the last essential element for the fitness of classroom practice incorporating ActiveClass was the professor's tolerance for using PDAs for "unapproved" activities such as instant messaging and playing games. Both of our professors took the view that it was their responsibility to create an environment that attracted the students' attention, and thus tolerated such activities as long as they didn't distract other students in the class. In this case, the small display and pen-based input—cited as problems in the next section—were a benefit, as they induced minimal distraction.

The Physical Aspect. Students must use their PDAs within the constraints of the physical setting of the class and with myriad other physical artifacts. Our students' desks were designed to accommodate standard-sized notebook paper and no more, and are slightly sloped towards the student. Students' other artifacts typically do not require direct line of sight or a flat surface. For example, students regularly bring water bottles, placed between the students' legs or on the floor, where they can be easily reached by feel.

Like paper, use of a PDA requires line-of-sight access for reading and interacting, and it has a limited viewing angle. The PDA's small screen means that text on the screen is close together. Because most of what is on screen is clickable, some precision is required by users. Students complained that "I have trouble seeing which one I voted on" and "The screen is so small that I click the wrong thing." The precision required by ActiveClass demands that students place their PDAs as close to line of sight as possible. Consequently, PDAs end up competing with paper for desk real estate, leading to a large set of adaptive behaviors.

Some students, finding the management of additional objects inconvenient, chose not to use their PDAs. Some who regularly brought their PDAs did not always use them. Their explanations for this included "I don't use it unless other people do" and "I log in when the professor tells me to." In other words, the benefits they received from using the system were sometimes insufficient in their judgment to justify the coordination costs of incorporating the PDA into their practices.

Students using the PDAs incorporated PDA "postures" into their object-using practices, most to keep their PDAs within easy use-distance while maintaining the primality of paper as a working medium. Some students chose to balance their PDAs on the edges of their desks, supporting it with the fingers of their non-writing hand. Others chose to rest it on one of their legs. Still others implemented a "flying PDA" posture, where they held their PDAs above their heads in one hand while balancing their non-writing-arm's elbow on the desk or against their chest. Finally, a popular, if time consuming, PDA-management style was simply placing the device on top of the paper on top of the desk. When used this way, the PDA occludes much of the page, requiring frequent movement of the PDA.

A crucial disconnect between student practice with ActiveClass and without is in the relationship between ActiveClass and students' notes. For many students, note taking is a critical activity, forming a bridge between lecture material and out-of-class practice. ActiveClass, both because it is physically detached from students' notebook and because it contains content typically not found in notes, 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 a record of previous sessions in the system.

Students also needed to be accommodating of the technological faults of this new generation of PDAs, the ActiveClass system, and the campus's wireless network. It is well known that there is a low gradient between temporary, minor glitches and the abandonment of a technology. We found that many devices needed to be rebooted regularly. Other, more difficult to localize, technical frustrations with ActiveClass required regular attention by students. Sometimes, for example, PDAs refused to recognize the wireless network in the classroom.

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. For these reasons, we divide our analysis into two parts, experience and aggregate data analysis.

Experience. At this time we lack detailed observation of practices with ActiveCampus Explorer, because unlike ActiveClass, its use takes place at unpredictable and even unaccessible times and places. Yet in our own use of ActiveCampus Explorer, our experience has not been unlike that of our character Sarah. However, as discussed below, these results were achieved in part by the the users refusing to be deterred by social, physical, and technical obstacles. What follows are a few examples of chance interactions and discoveries enabled by ActiveCampus Explorer.

- 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 stuck in a late meeting and sees that Pat is still in his office, despite the late hour. A quick message confirms that Pat will still be there in a half hour, and a much-needed meeting takes place.
- Bill is late for a meeting, but has to pick up some lunch first. The group waiting for him sees that he's in the "line" area 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.
- 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 only good croissants in the university area." Bill makes a note to try them sometime.

As found with the use of ActiveClass, there are considerable barriers to the successful use of ActiveCampus Explorer on wireless PDAs, but they are very different. Unlike with ActiveClass, there are few political considerations. The use of PDAs in social work settings is widely accepted, and they are relatively undistracting. Sounds are usually turned off, tapping on the screen makes little sound, and the display is small enough that it does not attract others' attention. In other realms, however, there are numerous new challenges, driven by the less structured, more dynamic environment in which ActiveCampus Explorer is expected to be used.

PDA Design. For one, wireless PDAs have limited battery life, typically under 4 hours with wireless connectivity. A typical day could keep a person away from their desk or a reliable power source for anywhere from 90 minutes to 16 hours. Nor is it easy to configure the PDA's to cyclically wake and sleep to conserve power. Often a running application or the networking itself will keep the PDA awake, draining the battery. Worse, PDAs predominantly have dynamic RAM storage, so if the main and backup batteries die, the PDA's settings must be restored. Such a restore requires considerable time, determination, and some technical savvy. Most wireless networking drivers may hang permanently if they are moved from one wireless hotspot into a deadzone, requiring a reboot or wireless card reset to restore connectivity. Also a consideration is tediousness of using the stylus to send (non-standard) messages and the like.

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 overcome much of 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. One solution to this problem is to turn a PDA into a server that accepts TCP/IP connections for content push. However, this introduces considerable non-portable client-side code, and does not work behind firewalls due to the one-way nature of network address translation (NAT).

Physical Constraints. With a PDA and software infrastructure that make it difficult to reliably wake a PDA periodically and push alarms to a user, it is best for a person to keep the PDA on and within view, or at least handy. Thus, the PDA must be conveniently carried and held. Most men have good solutions in loose shirt and pant pockets, but women's clothing is typically lacking these affordances. Also, placing a PDA on a flat table often leaves it at an angle where it is hard to read the screen; the PDA must be picked up to read it. Indeed, we have sometimes seen people propping up their PDAs with the edge of a book or even a pencil.

With these considerations in mind, we now look at ActiveCampus Explorer use from an aggregated statistical perspective from its initial release in April 2002 through May 2003.

Usage Statistics. One purpose of launching ActiveCampus Explorer with ActiveClass, as well as the Sixth College Explorientation was to create a structured context for students to use ActiveCampus Explorer. These events, then, were useful both for generating short-term data in a somewhat controlled setting, as well as providing the opportunity for bootstrapping an virtually mediated educational community, or at least getting a sense for how one might behave.

The launch and Explorientation activities ensured that gave user the opportunity to try out each feature. One of the key questions is whether and to what extent the features, in aggregate, are self-sustaining. How does the new user recruitment rate compare to the rate at which users drop out?

ActiveCampus maintains a database containing substantial information about how features were used. We extracted, in anonymous form and without any message content, a log of when messages were sent and graffiti posted. Each user was assigned a random identifier so that it was possible to see which actions were taken by the same person without identifying the person.

Measures based on the number of messages or graffiti gave excessive weight to a few heavy users, especially for messages. We instead examined how many distinct people were creating content for each feature, sending messages or posting graffiti.

These measurements form a baseline that we plan to use to evaluate the effect of future interventions, such as changes to ActiveCampus Explorer.

The top chart in Figure 4 shows the number of distinct individuals who created each type of content during each month. The peaks correspond to launches, months during which particular sets of users were positively encouraged to use ActiveCampus Explorer. 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

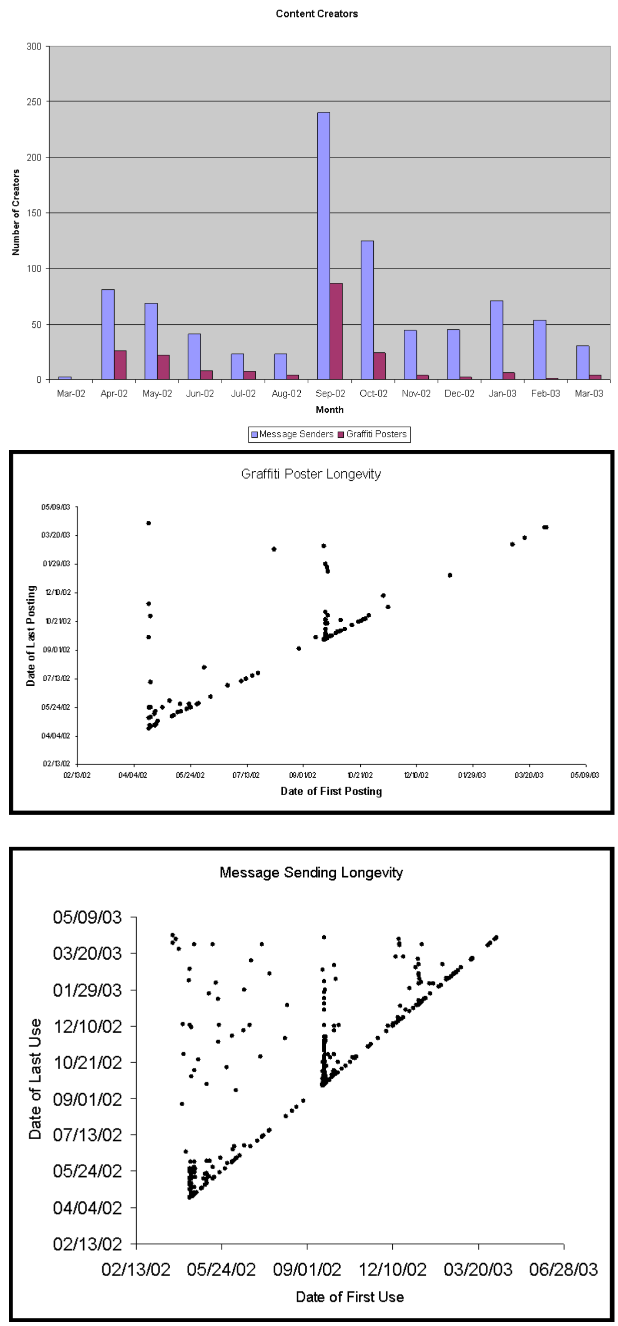

Figure 4: Messaging and graffiti creation statistics.

these are members of the ActiveCampus project.

The middle and bottom charts in Figure 4 examine the time span over which individual persons were content creators. Both charts plot the most recent date a content creator generated content against the first date on which the same content creator did so. The main diagonal represents people who experimented briefly, so that the first and last dates are close together. Vertical groups of points represent cohorts who first used the feature at about the same time. Points near the top edge represent people who generated content shortly before the data was extracted. Through an indirect method, 23 users on these charts were identified as members of the ActiveCampus team, and over 500 users from the general population.

Both features have many people who used the feature briefly, especially during launches or the Explorientation. Most of the few long term graffiti posters were recruited during these special events. On the other hand, messaging has long term users starting at any time, not just during special events. One possible explanation is that users of messaging bring it to the attention of friends and colleagues. Others are that there are deep needs for messaging as well as being a relatively mature and well understood technology.

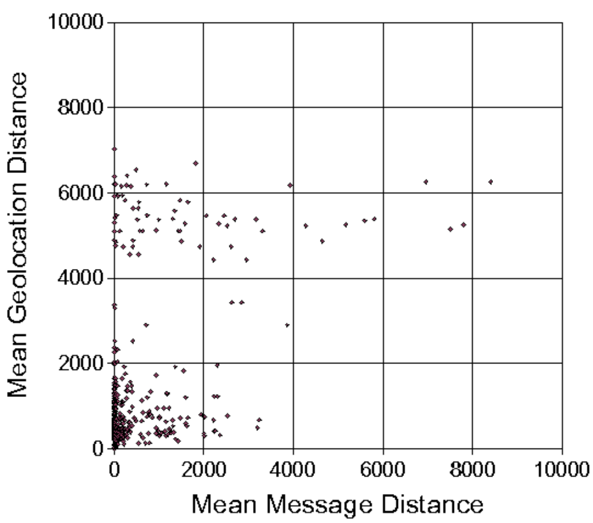

Figure 5: Messaging distance versus average distance between sender and receiver.

Since one of the underlying principles of ActiveCampus is that location does matter, the next phase of the analysis consider sender and receiver locations. This analysis was limited to the 1597 messages for which, at the time the message was sent, both sender and receiver 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 an intentional decision by the user to not disclose location. Also, the receiver of a message may not be logged in to ActiveCampus Explorer at the time. It should be recognized that a person is not always sitting at their device, and so distance between buddies is in fact a distance between their PDAs. It should also be realized that the geolocation algorithm can be inaccurate perhaps up to 100 feet due to signal fading in the 802.11b signals or an insufficient number of access points to triangulate against.

To get a first look at the relevance of location, we charted the average distance between each pair sender-receiver pair over time relative to their average distance at the time of messaging each other (See Figure 5). To our surprise, we observe that the vast majority of messages are sent when people are closer to each other than average. When the data is disaggregated we also observe that the vast number of messages are sent at very close range, with the median distance being about 50 feet.

Although we hesitate to hypothesize as to the reasons for the messaging distance being closer than average, one possibility includes that the sender of the message perceived the short distance, providing an impulse to communicate, perhaps to meet. Given that so many messages are sent at a very close distance, another possibility is that the pair are actually in the same room and are using instant messaging as a back channel.

4 Conclusion

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

Yet, considerable progress remains to be made. Mundane issues such as limited battery life, loss of data, and inconsistent communication make these applications difficult to use. These issues are certain to be resolved soon, but they illustrate the sensitivity of technical innovation to material circumstances. The office and business travel environments in which PDAs have traditionally flourished do not present these challenges to the same extent. Moreover, the professionals who are the dominant PDA users can afford accessories such as spare battery packs.

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, but SOAP standards over other network protocols are on the way.

The social barriers to handheld computing are perhaps the most significant. As computing moves into public spaces, issues of regulating access, sharing resources, and acceptable use remain to be resolved. The approach that emerged with ActiveClass is to put the power of negotiation into the application itself. It's not clear if these ideas can be extended to ActiveCampus Explorer. Although its buddy visibility policies have some of that character, it is difficult to tell at this time what effect they have had.

A surprising implication from our work is that location may matter in context-aware handheld computing. The fact that students at UC San Diego are more likely to message each other when they are closer than average is a tantalizing observation.

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