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Sharing Mobile Multimedia Annotations to Support Inquiry-Based Learning Using MobiTOP*

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Abstract. Mobile devices used in educational settings are usually employed within a collaborative learning activity in which learning takes place in the form of social interactions between team members while performing a shared task. We introduce **MobiTOP** (**Mobi**le **T**agging of **O**bjects and **P**eople), a geospatial digital library system which allows users to contribute and share multimedia annotations via mobile devices. A key feature of MobiTOP that is well suited for collaborative learning is that annotations are hierarchical, allowing annotations to be annotated by other users to an arbitrary depth. A group of student-teachers involved in an inquiry-based learning activity in geography were instructed to identify rock types and associated landforms by collaborating with each other using the MobiTOP system. The outcome of the study and its implications are reported in this paper.

1 Introduction

As mobile devices increase in popularity and functional features, it not surprising that they have been adopted for use in education [17]. In such settings, they are usually employed within a collaborative learning activity where learning takes place in the form of social interactions between the team members while executing a shared task [6]. Mobile devices are suited for collaborative learning because they allow students to take control of the hardware without being impeded by cumbersome instruments [5]. The learning activity could take place indoors (e.g. [21]) and/or outdoors (e.g. [16]) and could be highly relevant to subjects such as geography (e.g. [19]), biology (e.g. [20]) and history (e.g. [4]).

Mobile devices are best used in learning situations as a tool to support group activity as such learning activities involve sharing of students' interpretations of the situation

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and the environment with one another [18]. These devices make it possible for students to communicate with others and engaging with the environment without the need to constantly look at the screen [14], thus facilitating collaborative learning.

Within the area of geography inquiry, mobile devices have been deployed in fieldwork studies. Fieldwork has become an essential part of geography learning as it enables students to apply what they have learnt in the classroom in authentic outdoor settings [11] by active engagement and collaboration. Indeed, both classroom learning and field-based learning are complementary in geography education, to enrich the student's learning experience [3]. Moreover, students can use mobile devices to conduct social interactions that are no longer confined to those in the field but also extended to those who are at other locations (e.g. [1], [7]).

In this paper, we introduce **MobiTOP** (**Mobi**le **T**agging of **O**bjects and **P**eople), a geospatial digital library system that allows users to contribute and share geospatial multimedia annotations. A key feature of MobiTOP suitable for collaborative learning is the hierarchical annotations that allow annotations to be annotated by other users to an arbitrary depth, essentially, creating threads of discussions. MobiTOP served as a platform for a geography study conducted by a group of student-teachers. The goal was to identify rock type and associated landforms for an assignment. The students communicated through the hierarchical annotations afforded by MobiTOP, each comprising textual information and images. We highlight the experiences of the students and the lessons learnt. Data was collected from observations made during the study and questionnaires that were distributed to the students after the exercise.

The remainder of this paper will elaborate on the design, development, deployment and evaluation of MobiTOP. Section 2 presents the MobiTOP system. This will be followed by the description of the geography inquiry. Sections 4 and 5 highlight the observations made and the results of the evaluation from the study. The paper concludes with a discussion on the implications of our findings together with the possible areas of future work.

2 The MobiTOP System

MobiTOP is built upon an earlier geospatial digital library system known as G-Portal ([10], [12]) which supports the identification, classification and organization of geospatial and geo-referenced content on the Web, and the provision of digital services such as searching and visualization. MobiTOP offers an updated AJAX-based user interface as opposed a Java-applet interface to facilitate more widespread use, and enhanced mobile user interfaces. Another key difference is its hierarchical multimedia annotation support which allows users to create, share and organize media-rich annotations anytime, anywhere. In MobiTOP, annotations consist of locations, images and other multimedia, as well as textual details augmented by tags, titles and descriptions. Tags are freely assigned keywords [15] that are not limited by any taxonomy, ontology or controlled vocabularies. MobiTOP employs a client/server architecture (Figure 1) and consists of a single server and two independent mobile and web clients. At the server, the annotation database stores the annotations with the georeferenced locations and attached media.

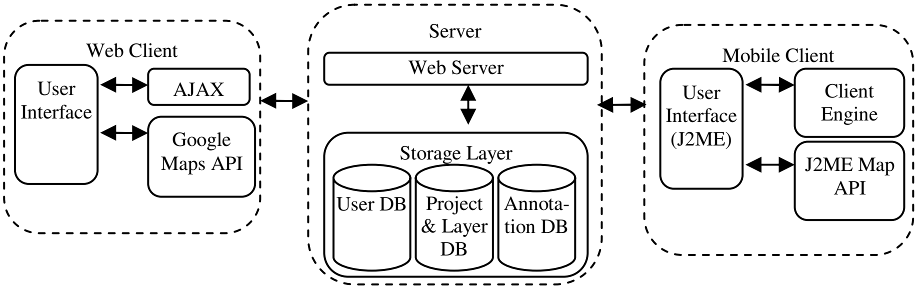

Fig. 1. Architecture of MobiTOP System

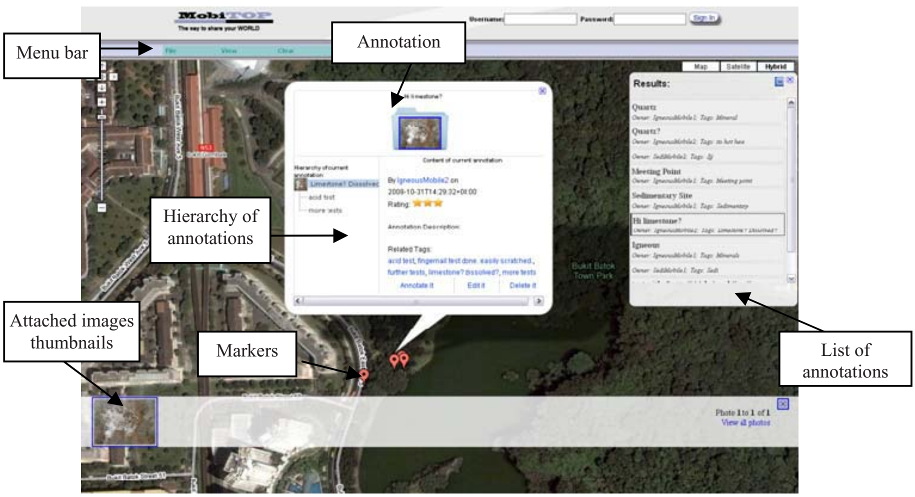

Fig. 2. User Interface on the web client

The Web client displays a map-based visualization for exploring contributed annotations using the Google Maps™ API. It also uses an AJAX library to enrich the user experience with sophisticated interactions. In Figure 2, the top bar displays the different functions available to the users, such as viewing all annotations on the map, and enabling the notification of updates. These georeferenced annotations consist of title, tags, description and photos in addition to the latitude and longitude. Each marker on the map represents a root annotation, and indicates that there is at least one annotation on that location. The panel on the right lists the available root annotations. Selecting one of the annotations in the list will display the content of the annotation and the sub-annotations associated with it on the map. Sub-annotations are displayed in a modified tree-view structure which displays only three levels of the hierarchy, consisting of the current annotation, parent and children, at any one time. This design is meant to reduce clutter on the interface as well as minimize information overload when many annotations are contributed. Further, a folder icon indicates that there are images attached to the annotation. Thumbnails of the attached images are shown in a banner displayed at the bottom of the map. The user interface was designed based on the outcome of a participatory design workshop where potential end users of MobiTOP took part as designers [9].

MobiTOP's mobile client supports a map-based visualization for exploring hierarchical geospatial annotations and location-based mobile annotating. The mobile client was primarily developed for Nokia N95 8GB smart phones (Figure 3). The client uses the global positioning system (GPS) feature available in the phone to determine the current location of the user.

The client's functions are logically organized into tabs (Figure 3). The left and right direction keys are used to navigate between the tabs. Users are able to create root annotations by accessing a form directly or by selecting a location on the map. At the form, the user can capture images using the phone's camera or select an existing image to be attached to the annotation. In order to annotate an existing annotation, the user selects the parent from the hierarchy before creating a new child annotation.

Fig. 3. MobiTOP mobile client

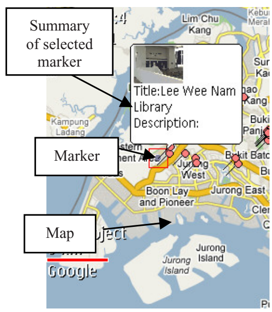

Fig. 4. Map interface of mobile client

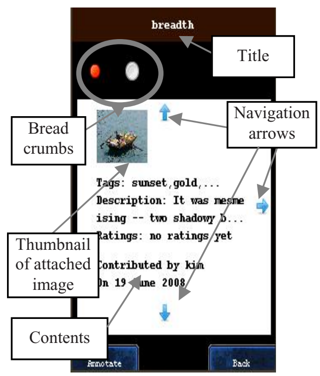

Fig. 5. Mobile client hierarchical visualization

Similar to the Web client, the mobile client displays annotations in a hierarchy. However, the challenge is to fit the information-packed visualization onto a small screen of the mobile phone. At the same time, the design should support a seamless integration with the Web client. Here, the design for the mobile client was again based on the outcome of a participatory design workshop [9]. Figure 4 shows the map-based visualization with a summary of a selected root annotation, while Figure 5 shows the interface for navigating a hierarchy of annotations. Users can use the navigation keys to open other annotations associated with this current annotation: parent (Up), children (Down), sibling (Left/Right). Based on existing mental models of navigation, users would be able to map the association of using the direction keys for navigating to the other annotations [2]. Bread crumbs are used to indicate the current level of the annotation in the hierarchy helping users to keep track of their locations in the annotation hierarchy. Here, the first dot denotes the root level, while subsequent dots indicate the respective level in the hierarchy.

3 Geographical Study of Rocks Using MobiTOP

A class of geography student-teachers from a teacher training institute was involved in the field study. One of their learning goals was to examine the type of rocks at a given location. Additionally, they had to explain the landform which was present at the site by identifying the type of rocks. The students were divided into two groups which were to identify two different types of rocks: igneous and sedimentary. Each group was assigned the task of identifying one of the rock types and comprised of field investigators and lab investigators. The field investigators were to go to the actual site to collect information and collaborate with the lab investigators who were in the classroom. Altogether 12 students were involved. They were divided evenly into the two groups. Four members of each group were assigned to be field investigators and the rest were lab investigators. The students' ages ranged from 23 to 26 and consisted of three males and nine females.

The students were introduced to the MobiTOP system prior to the actual field study. The concept of hierarchical annotations and their possible use in the fieldwork study were also explained to them. The roles and their respective tasks were highlighted as well. In the actual fieldwork exercise, four mobile devices were deployed, with each field team having two mobile phones. The field investigators within each group were not told of the specific types of activities they had to perform to meet the objectives of the study. Tools, such as a geologic hammer, magnifying glass and a small bottle of diluted hydrochloric acid, were also provided.

The lab investigators were stationed at the geography lab at the institute. Communication between the field and lab investigators was achieved through the MobiTOP system. The field investigators in each group collaborated, utilized the tools on the rocks and created annotations of their findings before uploading them to the MobiTOP server. As part of the creation of annotations, they took photographs as evidence to substantiate their findings. When the lab investigators received the new annotations, they replied with possible tests that could be easily conducted, description of the rocks, or the possible types of rocks. At both field and lab, the students' interactions with the application were recorded for later analysis.

Finally, based on the information gathered from the fieldwork, the group members were to consolidate and present their findings. Questionnaires were distributed to evaluate the application afterwards. The different groups of investigators were given different sets of questionnaire depending on the type of application that they had used (mobile or Web). The first part of the survey consisted of questions related to the demographic profile and the frequency of using various Web and mobile services. The second part asked the students to rate the usability and usefulness of the applications that they had used during the fieldwork. In this section, they were also asked open ended questions about the applications' features.

4 Observations

Video recordings that were made during the study served as a guide to elicit the students' usage patterns of the MobiTOP system. The recordings also provided evidence on the student's behaviors. Here, the recordings were analyzed and categorized according to various themes, described in the following sections.

4.1 Aesthetics and Layout

- **Color and icons.** Investigators commented that both mobile and Web clients had aesthetically pleasing designs. The Web client's main focus was the map and it seemed that the lab investigators were familiar with map navigation. For the mobile client, the icons that appear on the navigation tab made it easy for the field investigators to understand the available functions.
- **Tabbed navigation.** The different functions in the mobile client were organized using tabs. This made it easy for the field investigators to navigate to the different functions available. Tabbed navigation was proposed as all the tabs fit into one row of the screen so that it remained clutter free. At the same time, more controls could be fit into a single screen.

4.2 Navigation/Browsing of Annotations

- **Notification of annotation updates.** It was observed that the lab investigators were not aware of new annotations that were uploaded by the field investigators. This is because the original design of the Web client does not update the annotations on the map automatically. Instead, the user is required to click on an update notification message to refresh the list of annotations. This was done to give the users more control over the visualization. Specifically, a constraint in the Google Maps API meant that if automatic updates were supported, any open annotation window would be closed whenever the map was refreshed with new annotation markers, possibly causing surprise to users in the midst of reading an annotation. The semi-automatic update method was meant to let users choose when they needed to see the updates. However, it appears that this update notification was not obvious to the lab investigators as they asked the research team how they would know if there were updates repeatedly. A more prominent update notification is therefore needed.
- **Visibility of updates.** Newly created sub-annotations were not apparent to both users of mobile and Web clients when replying to annotations. There was no indicator on the root annotations stating that there were new replies available. Instead, the investigators had to navigate through all the annotations in the client to check for replies. As a result, some annotations were missed and were not replied to. This occasionally led to miscommunication between the field and lab investigators as the missed annotations contained pertinent findings for their activity. At other times, they were frustrated as they had to browse through the annotations to find that no updates had been received. Similarly, there were no markers or labels for updated/new annotations in the Web client because adding more than three levels of a hierarchy would increase the number of horizontal scrollbars in the left column of the annotation window (Figure 2), compromising the aesthetics and balance of the annotation window. Further, the mobile client did not have any markers or labels to indicate newly created annotations on the map due to the limitations of the J2ME Map API which did not support additional labels to be overlaid on the map markers. Thus, only notifications of updates could be made via status messages.

4.3 Creating Annotations

- **Uninformative titles and tags.** Titles and tags created were sometimes not informative. One of the root annotations had the title, "Hi limestone?" which was not appropriate. Likewise for tags, some annotations were assigned terms such as "its hot here", "dissolved?" and even '.'! This was probably due to unfamiliarity with social tagging as ten of the students reported to have not often used social bookmarking sites. Annotations with such titles and tags were more prevalent in those created by the field investigators. One possible reason was that the investigators could be new to such fieldwork and the instructor was not supposed to provide guidance. Another reason could be due to the limited input entry on the mobile phone, which will be explained in a subsequent section.
- **Notification of upload progress.** Due to slow network connections, the mobile client was not very responsive at times, especially during uploading. Here, a notification with the status of the upload (success or failure) is the only response the field investigator will see. The lag time between the selection to upload and the appearance of this notification caused some confusion as they did not know if any activity was taking place. For instance, the field investigators often had to be reassured by either the onsite researcher or their professor that the annotations that they had created were in the process of being uploaded.
- **Poor image quality.** Some images taken by the field investigators were not clear, which led to frustration of the lab investigators. With the poor image quality, the lab investigators were not able to compare with the rock samples in the laboratory. At the same time, they were not able to discern the characteristics of the rocks from the images. The camera function in the mobile client had basic functions but had no sophisticated features such as zooming.

4.4 Unfamiliarity with Mobile Phones

- **Multiple special keys.** As the mobile phone was equipped with multiple special keys for various features such as navigation, the field investigators often unintentionally pressed keys leading to unexpected results. For example, some investigators inadvertently pressed the mobile phone's "application" key causing MobiTOP to be hidden in the background. In general, it was difficult for the field investigators learn the purposes of the various keys in such a short time. This often led to errors that required the onsite researchers to intervene.
- **Poor affordances for data entry.** The field investigators were told to avoid using typical SMS short forms. This led to some frustration as they had to spend time keying in the full text of the annotations. Another factor that contributed to this observation was that none of the investigators had prior experience in using this particular mobile phone model (which is a high-end model at the time of this writing). Their unfamiliarity with the mobile phone made the students feel the keypad was restrictive, hence hindering their efficiency.

5 Usability Evaluation

We adopted the heuristic evaluation approach to ascertain MobiTOP's usability. Heuristic evaluation identifies usability problems by allowing the evaluators to examine the interface and then proceeding to make judgments to its compliance to the heuristics. In the questionnaire survey, investigators were asked questions based on Nielsen's 10 usability heuristics [13]. Additionally, the students were also asked to evaluate the system in terms of effectiveness in contributing to team collaboration.

Table 1 shows the results of the usability evaluation and Table 2 shows the results of the team collaboration evaluation. Both tables show the mean and the standard deviation of the values obtained for both Mobile and Web clients. In Table 1, the students found the mobile application to be relatively usable in general. For instance, the terms used in the mobile client were familiar to frequent mobile phone users. They thus had a sense of recognition of the features of the client, and thus mentally map these features to their expectations easily. Likewise, the consistency of the user interface helped in the learnablity of the system for some of the students. Similarly, the lab investigators found that language used and the layout in the application to be consistent. For example, the menu labels (e.g. "File", "View") were consistent with the conventions of a typical web application. They also felt that the labels used were understandable. Additionally, they felt that the map-based Web client was quite intuitive. This could be due to their familiarity with Google Maps as three of the lab investigators used Web based mapping applications somewhat frequently.

Table 1. Usability evaluation results (1 = strongly disagree; 5 = strongly agree)

No.	Heuristic	Mobile client		Web client	
		Mean	SD	Mean	SD
1.	Visibility of system status	1.75	0.71	2.50	1.29
2.	Match between system and the real world	3.00	1.29	3.25	1.50
3.	User control and freedom	2.50	1.07	2.50	1.00
4.	Consistency and standards	3.50	1.16	3.88	0.90
5.	Error prevention	2.71	0.95	2.00	1.15
6.	Recognition rather than recall	2.25	1.04	3.00	1.15
7.	Flexibility and efficiency of use	1.88	0.83	1.25	0.50
8.	Aesthetic and minimalist design	2.38	0.74	3.00	1.15
9.	Help users recognize, diagnose and recover from errors	2.75	0.71	3.00	1.15
10.	Help and documentation	2.75	1.28	3.00	0.82

In terms of usefulness for team collaboration, students felt that it was somewhat easy to view and create annotations. Perhaps factors like the phone's affordances and difficulty in the keying in of input contributed to the lower scores. However, they reported that that the mobile client allowed them to take photographs easily. One issue that emerged was that the field investigators were not able to communicate with the lab investigators easily. As highlighted, this was probably attributed to difficulty in finding the new annotations. On the other hand, the lab investigators were able to find the annotations that they needed easily. The list of root annotations in the right panel (Figure 2) probably helped them locate the newly uploaded root annotations quickly. They felt that notifications of new annotations could be improved by supporting automatic updates.

The students were also asked how they felt about the task and the applications. The open-ended questions elicited their opinions about the potential of the MobiTOP system as a learning tool. Additionally, they were also asked about useful features and those which could be improved.

Table 2. Usefulness for team collaboration results (1= strongly disagree; 5 = strongly agree)

No.	Actions	Mobile client		Web client	
		Mean	SD	Mean	SD
1.	Create annotations easily	2.63	1.06	2.88	0.66
2.	View annotations easily	2.75	0.89	2.25	0.96
3.	Take photographs easily	3.88	0.83	2.25	1.26
4.	Find annotations that you need easily	2.14	0.38	3.50	0.58
5.	Notifies new annotations created by other investigators	1.88	0.83	2.00	0.82
6.	Communicate with the lab investigators easily	1.75	0.71	2.25	0.96

Mobile Client. In general, the students appreciated the real life aspects of the fieldwork activity as it gave them the opportunity to discover for themselves facts which are not found from textbooks. The students were divided in their opinions in terms of the potential of the application as a learning tool. Half saw the potential while the other half did not feel the same way. From the perspective of one student who concurred, the application was helpful for fieldwork as the mobile phone was equipped with useful functions ("considering the availability of GPS tools and Internet on the mobile phone, it can be very helpful"). Other views included that MobiTOP was a useful for them to share and collaborate with other users. In contrast, those who did not agree felt that the problems encountered during the usage of the application marred its potential as a learning tool ("There are too many problems and errors with the tool"). These problems include the usability of the hierarchical annotations ("Only if the annotations appeared in a user friendly manner") and the latency of retrieving annotations ("(only) if the time taken to be reflected (on the map) is shorter"). The fact the MobiTOP system is still in the prototype stage can account for many of these issues.

One of the features that students found favorable was MobiTOP's built-in camera feature for annotations. Students were able to take images without changing the orientation of the mobile phone and by pressing a button on the keypad instead of the camera shutter button. This helped them capture images easily as their other hand might be occupied with notebooks or tools. Another feature that students found useful was the ability to view annotations on the map. This helped them better understand natural rock formations as they were able to pinpoint the exact location of the sites and observe that which were quite close had different types of rocks.

However, the constraints of the mobile phone did pose problems. One student felt that the mobile phone's screen was too small to locate annotations easily. This sentiment was echoed by several other students ("the phone is too small an interface (to display a map)"). As the annotations required the user to press a button to update the annotations, one student felt that the "annotations should be refreshed by itself … (for example) appear(ing) like a text message." Another student suggested that "a more sophisticated platform will be better, maybe a Blackberry."

Web Client. The lab investigators felt that they could only slightly appreciate the context of the work. One of the reasons for this outcome was that they were not able to see the rocks in their natural formations making their learning somewhat ineffective. Another contributing factor could be due to the lag time between receiving the notifications of new annotations. They spent their time discussing about the findings of their classmates while waiting for the outcome of their instructions.

When asked about the application as a potential learning tool, again, opinions were divided. Some felt that it had such potential ("technology is highly used in school(s) and such tool could be used for field work like what was done"). The rest felt that the application was "too tedious and time consuming". This was primarily attributed to the lack built-in communication facilities to enable lab investigators to track the status of the field investigators. For example, the lab investigators kept checking for updates while the field investigators were making their way to a different site. This led one of the lab investigators to remark that she had already lost interest in the activity.

Despite the problems, students found that being able to create annotations and placing them on the map was a useful feature. This demonstrates that the students were able to appreciate the information creation and sharing aspect of the MobiTOP system. Another positive feature noted by the investigators was the ability to associate images with annotations, which they found useful for learning. Perhaps they understood that augmenting the annotations with photos would enrich the user experience. Others commented that they felt the application enabled them to communicate with the field investigators in an almost synchronous manner. Finally, some of the features in the Web client that students would like to see improvements on are automatic updates of annotations ("easier notification of new annotations") as well as easier navigation between root annotations. Another crucial point made is that they would like to see an improvement in the ability to communicate with the field investigators easily ("communication with the field group should be made easier").

6 Discussion and Conclusion

This paper introduces the MobiTOP system and describes the outcomes of its use in a geography study. From our investigations, three main findings emerge. First, training is essential when introducing a new technology. In our study, some of the field investigators were not familiar with the terms used and the mobile phone model. Although all students were experienced mobile phones users, they needed some time to get themselves acquainted with the phone's keys and functions, mainly because of the usability problems found in smart phones [8]. This usability issue is often the product of the increasing number of features at the expense of usability. As the students did not own this particular phone model, problems during the fieldwork activity emerged. Perhaps the familiarization activity could be a take home exercise where students experimented with the phone over a longer period of time.

Secondly, the affordances of the mobile device should be taken into consideration when developing applications [14]. In our case, textual input should be minimized to counteract uninformative titles and tags. Both titles and tags are intended to give an overview of the annotations so that other users would be able to quickly understand the contents of the annotation. For example, titles of the root annotation could be automatically reused by the sub-annotations so that there is a flow in the thread. Further, the client could suggest tags based on an analysis of other annotations in the same thread, or on annotations nearby. However, users should have the ability to override these default values to meet their specific needs.

Thirdly, based on our observations of the investigators and their feedback in the survey, the following design lessons can be drawn from this study:

- Provide timely and informative updates in dynamic, information rich environments. In MobiTOP, indicating new contributions to the system would enable users to make serendipitous discoveries of information which meets their needs. Further, indicating new contributions in a thread of annotations is equally as important. This is because users interested about the thread's topic would be able gain new perspectives.
- Provide adequate and informative feedback to users' actions in interactive systems for tasks that require time to complete. Users expect a timely response to their actions in such systems so as to ensure that they would know the next step to take in order to fulfill their goals.
- Additional communication channels may be helpful. Apart from the asynchronous communication support afforded by the hierarchical annotations in MobiTOP, some users in the geography study commented that synchronous communication modes would be useful as well.

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