LetsPic: Supporting In-situ Collaborative Photography over a Large Physical Space

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ABSTRACT
Recent advances in mobile computing technology have made it increasingly common for collocated users to perform collaborative photography over a large physical space in various group activity scenarios such as field trips, site surveys, and group tours. Unlike traditional collocated interactions in a shared physical space, we find that mobility and group dynamics make awareness of group activities over a large physical space very challenging. In this work, we design LetsPic, a group photoware that supports group awareness for in-situ collaborative photography over the large physical space. We have iteratively built the app and performed user studies in site survey and group tour scenarios (n = 31, n = 24). Our results confirmed that LetsPic effectively promotes group awareness, facilitates group coordination, and encourages collaboration in both scenarios. We discuss practical design implications based on our findings.

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Collocated interaction; awareness; photoware; photography, collaborative photoworkCollocated interaction; awareness; photoware; photography, collaborative photowork

INTRODUCTION
A collocated environment is known to be ideal for group work [16, 17, 33] because close distance naturally facilitates awareness and collaboration [33]. Technological support has mostly been related to the use of the shared physical space with a tabletop [41] or a large shared display [48]. In this case, a physical space is small in size and members are typically in close proximity [41, 48]; hence, group awareness can be naturally maintained [17].

Recent advances in mobile devices have made it possible for a group of people to participant in various collaborative activities over a large shared space, ranging from site survey and field trips to citizen science, augmented reality games, community policing, and emergency operations [28, 49, 36, 2]. Owing to mobility and group dynamics, group activities may span a large physical space, which could be far larger than the physical space of traditional collocated interactions around a shared table or display.

This fact indicates that social interactions in a large physical space may include a mixture of collocated and remote social interactions, because subgroups/individuals could move independently. We define this environment as the 'activity space' that bounds group activities. Activity-space awareness refers to the up-to-date knowledge of group members' activity, location, and interaction in an activity space. This concept is similar to traditional shared workspace awareness, but its focus is mainly on mobile group work over an activity space. Prior studies on workspace awareness showed that maintaining awareness in an activity space is harder than in traditional collocated environments [19, 33]. Thus, there are unique design opportunities to support activity-space awareness to promote group activities over an activity space.

In this work, we focus on collaborative photography that involves a group of people taking photos together (e.g., a site survey and theme park tour). Collaborative photography is popular in both social and work contexts [5, 18]. It is increasingly common for collocated users to perform collaborative photography over a large physical space in various group activity scenarios such as education and research [5, 18, 22] or tour and leisure [6, 34]. Despite the popularity of collaborative photography in various domains, there is a lack of prior work on technological support in both the commercial and research domains. We explored design opportunities of activity-space awareness by iteratively developing LetsPic, group photoware for in-situ collaborative photography. The key design concept of LetsPic is to empower users with activity-space awareness to facilitate in-situ collaborative photography over a large physical space. LetsPic provides activity-space awareness on two different levels: i.e., overall progress (or global) awareness and localized level for subgroup activity awareness. To understand how these two levels of awareness facilitate collaborative photography, we performed two field trials in both work and social contexts, namely site survey and theme park tour scenarios (n = 31, n = 24). We intentionally studied these two contexts because the purpose of photography is different [23], and thus, we could observe more diverse patterns of behaviors influenced by activity-space awareness. Our findings showed that activity-space awareness helped group activity coordination and facilitated social learning and in-situ collaboration.

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The remainder of this paper is organized as follows. We begin by introducing the background and related works. We then present the details of our formative study and its findings. Next, we present design of LetsPic, followed by the result of two case studies. Finally, we present the discussion and conclusion.

BACKGROUND AND RELATED WORK

We provide a brief overview of collaborative photography and group work. We then define activity space for group work and overview prior studies on technological support for group work. After discussing how group awareness can be supported in photoware, we perform a comparative analysis of existing photoware for collaborative photography.

Collaborative Photography and Group Work

Collaborative photography involves a group of people taking photos together. There are various application domains of collaborative photography: 1) collaborative site surveys (e.g., site reviews, construction sites, and natural habitat monitoring [49]); (2) field trips (e.g., botanical gardens, zoos, and historical sites [22]); (3) group travel (e.g., theme park visits [6, 10, 12, 13]) and leisure/sports activities (e.g., outdoor festivals, marathons [20, 34]); (4) group photography tours and workshops (e.g., a visit by a camera club to scenic sites); (5) image-based research methodologies (e.g., geography, archaeology, and anthropology [37, 18]).

Collaborative photography may have different sharing goals (e.g., affective vs. functional sharing) [23] but it can be generally considered as group work. According to the literature, group work involves two types of work: taskwork and teamwork [16, 45, 44]. Taskwork is independent work performed by individual members (e.g., taking photos), whereas teamwork is interdependent work required to effectively coordinate taskwork and is critical for overall group performance (e.g., collecting quality photos on a given site). Prior studies have shown that groupware should support both taskwork and teamwork to facilitate group work [16]. Collaborative photography requires photo sharing to support teamwork, for which the enabling software is termed photoware [14]. Photoware supports various sharing and browsing features such as co-present/co-located sharing (e.g., a shared display) and remote sharing (e.g., instant messaging). Remote sharing is required because the physical space of collaborative photographic activities may span a wide area; for example, a few subgroups may travel separately in a large theme park [10].

Our main goal of this work is to explore how to build a system capable of supporting in-situ collaborative photography over a large physical space. Our formative study was limited to goal-oriented tasks of site surveys, because these tasks require a higher level of collaboration than other tasks and this resulted in elaborate design requirements. We initially evaluated the system in goal-oriented scenarios of site surveys; and subsequently we also tested whether our system is suitable for non-goal-oriented tasks by conducting a naturalistic user study at a theme park.

Activity Space for Group Work

Recent advances in mobile computing and wireless networking have enabled a group of people to engage in collaborative activities using their mobile devices in a shared space. Owing to mobility and group dynamics, group activities may span a large physical space (e.g., a theme park), which is far larger than the physical space of traditional collocated interactions (e.g., a physical space around a shared display [48]). Consequently, social interactions in a large shared space may include a mixture of both collocated and remote social interactions, as subgroups/individuals are able to move independently from one another. In any case, the key is that group activities are bounded within a shared space, and thus, we define social interaction within this environment as 'extended collocated social interaction,' and more broadly, we term this environment the 'activity space' that bounds group activities.

A vast amount of literature in psychology has commented upon the impacts of distance between people on the awareness, perception, communication, and collaboration between them and, since a shared physical space among group members is small in size, a traditional collocated environment is ideal for group work [33]. Thus, the shared physical space of the traditional collocated environment enables rich person-to-person interactions [17]. Group members can naturally be aware of others' activities and interaction intentions [33, 16, 17]. Such awareness is important for group activities in both social and work contexts. In social contexts, awareness promotes collective interactions and increases a sense of community among members [21], whereas, in work-based contexts, awareness enables members to effectively coordinate tasks, share resources, as well as transit between taskwork and teamwork [16].

Technological Support for Group Work

Technological support in collocated environments has mostly been related to the use of the shared physical space. Group members manipulate objects on a tabletop [41] or on a large shared display [48]. The physical space is small in size, and members are typically in close proximity [41, 48]; hence, group awareness can be naturally maintained [17]. For example, Personal Digital Historian is a groupware system that uses a shared physical space on a tabletop [41]. The shared physical space facilitates conversation and storytelling by allowing group members around the table to explore digital content together. Another example is We Space, a groupware system that uses a shared physical space around a large display to allow collocated groups to explore and visualize scientific data together [48].

If members are remotely located, it is difficult to maintain awareness, and thus, researchers have attempted to design software tools to provide group awareness [17]. For example, shared workspace awareness is enabled through virtual artifacts such as radar view or multiple-WYIWIS views [17]. Interestingly, not necessarily in a remote place, Wallace et al. [45] revealed that even in collocated environments, working on a *personal display* frequently prevents group members to naturally maintain awareness of other group members' activities and interaction intentions. Thus, Wallace and his colleagues introduced an additional display showing the overall progress of a group into collocated group work environments [45, 44].

Mobility in collaborative work has been of great interest in CSCW. There are several early studies on activity-space awareness. Luff and Heath studied how local mobility affects col-

	Grouping	Capturing	Sharing	Displaying & Monitoring			Reviewing	
	Private vs. Public	Custom Camera app	Auto vs. Manual	Photos	Contextual cues (global/local awareness)	Viewfinder embedding	Voting/ Commenting	Co-present
LetsPic	Private	Yes	Auto	Yes	Global + Local	Yes	Voting	Yes
Inst Messenger	Private	-	Manual	Yes	-	-	Commenting	Yes
Flickr	Mixed	-	Manual	Yes	Global	-	Both	-
Flipper	Private	-	Manual	Yes	-	-	Commenting	-
MobiPhos	Private	Yes	Auto	Yes	-	Yes	-	-
ImageSpace	Private	Yes	Auto	Yes	Global (Web only)	-	Both	-
Image Exchange	Mixed	-	Manual	Yes	-	-	-	-
InstaCampus	Private	-	Auto	Yes	-	-	-	-

Table 1. Feature support for in-situ collaborative photography

laborative work in the workplace, ranging from medical consultations to construction site checking and the London underground monitoring [28]. In a hospital setting, the AWARE platform supports context-mediated social awareness to enable group cooperation by sharing contextual cues (e.g., availability, activity, location) [4]. Beyond these examples, recent advances in mobile computing made it possible to enable a wide range of in-situ mobile group activities such as collaborative photography, citizen science, and mobile augmented reality games. However, most technological supports are still limited to *traditional collocated settings*. For example, Pass-them-around is a photoware system [26] that supports photo sharing by passing mobile devices around on a tabletop. PicoTables is a collaborative authoring system associated with a large display in which a collocated group can draw and project simple sketches using their smartphones on a large display [38].

Group Awareness Support in Photoware

Activity-space awareness is defined as the up-to-date knowledge of group members' activity, location, and interaction in an activity space. This concept is similar to shared workspace awareness, but its focus is mainly on mobile group work over an activity space. Group awareness support requires group members to make their activities visible to others, and also constantly monitor other members' activities (also known as displaying and monitoring practices) [40]. Similar to conventional photowork [24], we introduce the notion of 'collaborative photowork' as the activities that people perform in order to increase workspace awareness for collaborative photography. Photoware can provide the entire collaborative photowork process, i.e., (1) capturing, (2) sharing, (3) monitoring, and (4) reviewing. (1) Capturing is to use a custom camera app to capture photos. (2) Sharing of photos and meta-data could happen either automatically or manually. (3) The shared information such as thumbnail images and contextual cues (locations of photos) will then be displayed and monitored. Contextual cues about photo locations can be mapped globally, and/or can be localized from the perspective of photographers (e.g., nearby photos centered on a user's current location). Seamless monitoring without context switching can be supported by embedding display features (e.g., thumbnails and localized map views) into the camera viewfinder. (4) Finally, reviewing can be done with the co-present mode (synchronized reviewing) as well as online interactions (e.g., voting/commenting).

Comparative Analysis of Photoware

Our survey showed that existing photoware partially supports in-situ collaborative photography (see Table 1). One of the most widely used photo sharing tools for in-situ group work would be instant messengers (e.g., WhatsApp, WeChat, LINE, KakaoTalk), which support a shared virtual space for posting a series of photos and commenting about them. Existing photo sharing services (e.g., Instagram and Flickr) support manual/selective photo sharing with very preliminary displaying and monitoring options. Flipper is a mobile-based group-centric photo sharing system which organizes the shared photos on the basis of people for ease of browsing [7]. Mobiphos [6], which is designed to support group travels, provides real-time photo sharing over a viewfinder, but photo sharing is limited to collocated users due to the limited Wi-Fi range. ImageSpace allows users to capture photos with their mobile client and to spatially explore photo collection with web browsers (e.g., map and 3D viewing) [25]. Image Exchange [43] allows users to manually share photos in real-time and interact with one another via the cloud (e.g., posting comments). InstaCampus [11] supports automatic photo sharing with push notifications of newly captured photos, but there is lack of sharing contextual cues.

There are other types of photoware services such as location-based exploration, co-creation activities, and cooperative photography. Columbus allows a user to explore publicly shared photos located nearby the user on a map [39]. There are several co-creation services such as comics, photo-souvenirs, and cooperative/synchronous photography. MobiComics is a comic strip generating application tied to large displays in (semi-) public places [27]. Automics is photo-souvenir generating photoware developed for groups of visitors to theme parks [10]. Cooperative and synchronous photography includes remote cooperative photography (e.g., one as a camera and the other as a shutter as in ShareLens and RemoteShot; or one acting as a remote photographer and sharing photos [47]) and bullet time effect generation with multiple phones (e.g., CamSwarm [46]).

UNDERSTANDING COLLABORATIVE PHOTOGRAPHY

We perform a formative study to understand collaborative photography and discuss design requirements from our findings. In this section, we first explain the setting for participants and procedure for our formative study. Next, we discuss the findings of our formative study, followed by the design requirements we identify based on these findings.

Participants and Procedure

To understand collaborative photography practices, we conducted a formative study with participant-observation and focus group interviews. A total of 17 participants (four groups of three to four members) were recruited. Ten were female and

seven were male. The mean age was 21.7 (SD = 4.4) years. All participants were recruited by posting an article on an online bulletin board at a local community. In the introductory session, after participants read and signed the consent form, we explained the purpose of our study. Based on the results of the interview and those of previous work [18, 11], we designed a site survey as a collaborative photography scenario and observed our participants' collaborative photography behavior. In the site survey, participants were asked to collect the photos that will be used to create the introductory pages of three places on a university campus. These places were the most popular attractions for visitors as sculptures were exhibited. Each group performed our field exercise on a different day. During the exercise, two researchers accompanied the group and recorded field notes. After collaborative photography, we held focus-group interviews to discuss their behavior, concerns, and problems. The entire interview was recorded and transcribed for content analysis. We used affinity diagrams to identify key issues, and uncovered design opportunities for improving collaborative photographic practices [42].

Findings

Opportunistic exploration and collaboration

We found that collaborative photography involves the following steps: i) assigning photo spots, ii) taking photographs at the assigned spots, and iii) reviewing photos. The assigning/photography stages were iteratively performed, whereas reviewing was performed at the end. Members mostly gathered to assign photo spots to opportunistically explore, because they thought, *"It is easier to communicate with each other."* Photos were often taken while the members walked together. For example, after a group approached <Photo spot #1>, <Member #1> broke off from the group and started to take photos at <Photo spot 1>. The remaining members continued walking until they encountered <Photo spot #2>. <Member #2> broke off from the group to take photos at <Photo spot #2> while the others continued walking. After completing the assigned tasks, members naturally reunited and the process was repeated. Once members completed their photography at their photo spot, they tended to help the other members who were still taking photos. AP2 said, *"If one of us remained at the spot, I assumed that there were additional photos to take and this prompted me to go there to take pictures. If I saw someone who was still taking photos, I wanted to help."*

Lack of group interaction support

Participants used a group chat room using their instant messenger (i.e., KakaoTalk) for sharing photos, checking progress/location, and discussing photos. However, the messenger was only used often in the beginning, and was rarely used subsequently. Participants commonly experienced two problems. Participants reported that chatting interrupted their photography activity. BP2 stated *"I think it's inefficient to take a picture, talk to the person next to you, and use the messenger at the same time."* Thus, participants often ignored messages or replied later after taking photographs. Another problem was that photo sharing complicated conversing, as DP4 mentioned, *"the photos and the conversation appear on the same screen. [...] often it was full of photos."* Uploaded photos occupied more space than messages, as BP2 explained *"When I uploaded several photos for comments, it was frustrating to find others' comments because the photos and the comments were quite apart [...] I often scrolled up and down because there was too much space between a photo and the comment."*

Lack of activity-space awareness

Although participants were within sight of each other when members were dispersed, lack of communication and photo sharing adversely affected awareness and isolated the participants from each other. We found considerable evidence supporting that participants lacked awareness. We observed that individual members often revisited the same place others had already visited. Next, in the focus group, participants commonly reported that it was difficult to be aware of where the other members were and what they were doing while taking photos. For example, AP2 stated *"since the space is too large, it is quite challenging to know where the members including themselves took photos."* DP1 said *"I felt like I've been all around taking pictures and it was difficult to find a new place. So I just walked around again taking pictures."* This lack of awareness resulted in redundant photos. At the review sessions, all groups were surprised to find that they took many redundant photos, as CP3 commented, *"We didn't know we took many similar photos."*

Design Requirements

Our results showed that collaborative photography happens in an opportunistic fashion. Exploring and assigning photo spots happened with less coordination, partly because of lack of activity-space awareness–group members did not know well about the overall progress and individual activities. Group chatting was initially used for collaborative photography, but the chat room was rapidly flooded by photos, which prevented meaningful group interactions. Our participants all agreed that group interactions (i.e., sharing photos and conversing with one another) were important tasks for in-situ collaborative photography despite the lack of suitable tools. Furthermore, they emphasized the importance of knowing what other group members were doing and providing immediate feedback. CP2 commented, *"The reason why we should know about what photos the others took is because I want to take a picture at a different spot."* However, participants also expressed some concerns about delivering verbal feedback. For example, DP4 commented, *"If I'm taking pictures and if I have to give feedback to others', it will be difficult for me to concentrate on my pictures or give quality feedback."*

These observations suggest the following design requirements for improving collaborative photographic experiences. As collaborative photography happens in an opportunistic fashion, providing activity-space awareness is very important. Awareness should be supported in two layers: an activity-space level for overall progress awareness, and a localized level for subgroup activity awareness; owing to group dynamics, subgroups appear and subgroup-level collaboration happens opportunistically. During the activity, group members are typically occupied with capturing photos, and photo reviewing only happens occasionally. This means that, when enabling real-time awareness, it has to be carefully designed to minimize interruption. One approach is to augment a viewfinder with simple awareness information (e.g., recently taken photos by other members) and structured social interaction features (e.g., expressing likes). Furthermore, occasional photo review needs improved technical support, as sharing small screens

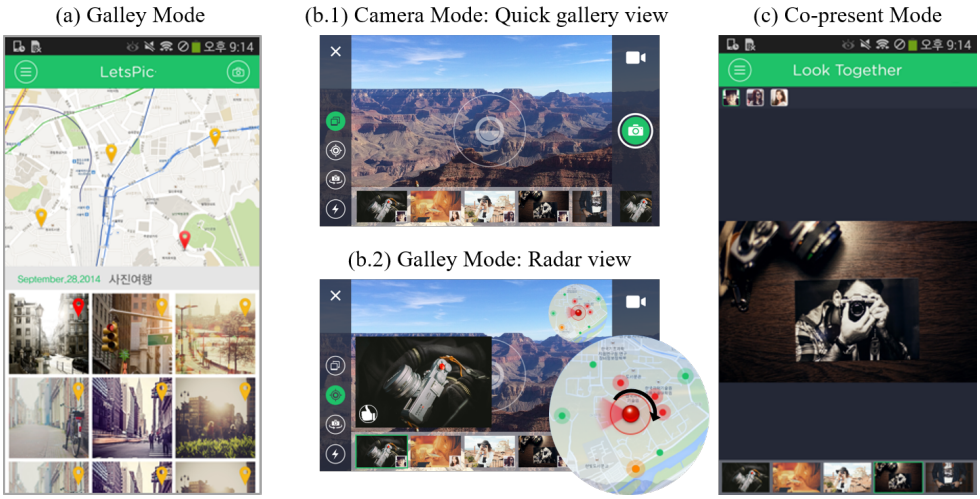

Figure 1. User Interfaces of LetsPic

is burdensome. The following requirements were carefully considered in our collaborative photoware design for in-situ collaborative photography.

LETSPIC DESIGN

We present LetsPic, a mobile camera app that supports in-situ collaborative photography over a large physical space. We interactively designed our app with several rounds of pilot studies. The key design concept is to empower users with activity-space awareness to facilitate collaborative photography. As shown earlier, limited awareness because of lack of communication and photo sharing made in-situ collaborative photography difficult and less efficient. LetsPic addresses this concern by employing three modes: (1) a *"gallery mode"* that allows users to provide detailed activity-space awareness (i.e., overall progress on an interactive map), (2) a *"camera mode"* that allows users to take photos while providing simplified activity-space awareness information (i.e., a sneak view of recent photos, and a map view of local subgroup activities), and (3) a *"co-present mode"* that supports collaborative photo reviewing with synchronized photo broadcasting.

Gallery Mode

The gallery mode displays a list of photos on an interactive map. The map shows the location of each photo as a colored marker to help users to maintain activity-space awareness. As each user uses a unique color, and thumbnail images are overlaid with users' profile images, users can easily obtain up-to-date knowledge of others' photos and the locations where the photos were taken. This mode also allows users to check each individual's activity with name-based photo filtering. Interactive-map-based visualization will encourage users to self-coordinate opportunistic exploration and collaboration. For example, a subgroup may decide to explore the places that other subgroups have not visited. Furthermore, we allow users to import photos that were taken by other camera apps.

Furthermore, to promote group awareness, we intentionally used the gallery mode as the initial landing page, and the remaining features were accessible from the gallery mode. For example, users could access the camera mode only from the gallery mode by clicking the camera mode button located at the top-right corner. Note that our gallery mode design is very different from that of existing photoware, where a map is basically used to filter nearby photos. As shown later, in our work we realized this kind of proximity-based filtering using a different approach (named "radar view").

Camera Mode

The primary feature of the camera mode is taking photos. There are three major components, namely, a viewfinder, a quick gallery view, and a radar view. The list of four buttons is placed at the left side. The four buttons from the top enable and disable the quick gallery view, the radar view, the selfie mode, and the camera flash.

Our viewfinder provides preliminary camera functions such as focusing, zooming, changing to selfie mode, and controlling the flashlight. The camera mode has two overlay views, namely a quick gallery view and a radar view. The quick gallery view displays recent photos taken by group members. Whenever group members take a photo, it will be automatically shared with all the other users and displayed in the quick gallery view. Each shared thumbnail includes information about the photo owner. A selected thumbnail will be enlarged. In an enlarged photo, LetsPic allows users to provide quick feedback by clicking a like button, and it also allows a photo owner to easily delete a photo (see Figure 1.(b.2)).

The radar view aims to facilitate activity-space awareness in close proximity for subgroup collaboration. In our initial design, we used an existing radar metaphor as in Gutwin et al. [17]. A small radar thumbnail was displayed on the top right corner. For a given user, the radar view allows the user to see all the nearby photos within a fixed distance. In our design, we set the radius to 50 meters, as this space is large enough for subgroup interaction. When a radar view is displayed, the quick gallery view shows only the list of the photos showing on the radar view; otherwise, it shows all the photos taken by group members including the current user.

Co-present Mode

The co-present mode is used to enable collaborative photo reviewing with synchronized photo broadcasting (named "Look Together"). While browsing photos in the gallery mode, any

user can start the co-present mode. All the group members will receive a co-present mode invitation. Members accepting the request will share the same screen. Any users can join the co-present mode as long as the mode is in progress. Our formative study shows that users typically review photos when they are physically nearby. Therefore, we allowed any user to have access to flip pages (i.e., a free-for-all policy [1]); we basically assumed that coordination takes place onsite, as confirmed in our pilot studies.

Software Architecture

In our implementation, mobile clients were implemented in the Android platform, and real-time interaction among members was mediated via a backend server. We set up a local Parse server, an open source implementation of backend-as-a-service. The backend server simply acts as a relay, and all the interactions take place on the client side. The backend server maintains basic information such as group metadata (e.g., member information), photo metadata (e.g., thumbnails, likes, and GPS location), and co-present status (e.g., participants). When a new thumbnail becomes available, or a new co-present request is initiated, the backend server sends a push notification to all the clients, and the corresponding handlers are processed at the clients. That is, clients pull the updated content from the backend server to update their views. In the camera mode, update requests will be processed only if the quick gallery or radar views are enabled.

Understanding User Experiences of LetsPic

To explore the user experience of LetsPic, we performed case studies in both work and social contexts, namely the site survey and theme park tour scenarios. The purpose of photography in the site survey scenario is to collaboratively collect quality photos in a given area. In contrast, the purpose of photography in the theme park tour scenario is riding and sightseeing with taking photos embedded in these activities. We expected that providing activity-space awareness in work and social contexts would have different results since their purpose of photography are different (functional vs. affective) [23]. We first performed the case study for the site survey scenario, followed by the case study of the theme park tour scenario.

STUDY 1: SITE SURVEY

Participants and Procedure

We recruited 12 groups of two to four members through ads on a bulletin board of an online campus community. In total, 31 participants were recruited, of which 16 and 15 were male and female, respectively. The average age of our participants was 21.5 (SD = 4.2) years. All group members were friends. All the participants were university students and had at least one experience of a field trip in their respective high schools. Participants received USD 21 as compensation. We randomly assigned groups into four conditions: LetsPic_A, LetsPic_B, Camera_A, and Camera_B.

Prior to our study, we first instructed our participants and asked them to read and sign a consent form. Then, each group performed two sessions of group photography exercises and completed a post-questionnaire, followed by a focus group. For the group photography exercise, similar to formative study, we asked participants to create orientation guides for two places on a university campus. Note that our formative study and the site-survey study followed the study design of a previous study [11]. For each session, groups performed the exercise using different applications (LetsPic and Camera) in different places (Place_A and Place_B). For example, groups in the LetsPic_A condition were first asked to conduct the exercise using the LetsPic app in Place_A and, then, to use the camera app in Place_B. During the exercise, two researchers accompanied each group and took field notes.

After finishing each session of the group photography exercise, groups completed the post-questionnaire about groupware usability [16] and generic usability questionnaire [29]. The groupware usability questionnaire consists of 21 items measuring how an application supports seven important activities in collaboration (Gutwin et al.'s mechanics of collaboration); explicit communication, consequential communication, coordination of action, planning, monitoring, assistance, protection [16]. Participants rated each item on a 5-point Likert scale, labeled from "Strongly Disagree: -2" to "Strongly Agree: +2." The generic usability questionnaire consisted of 30 items measuring the usability of an application in terms of its usefulness, ease of use, ease of learning, satisfaction [29]. Each item was rated on a 7-point Likert scale, labeled from "Not Very Likely: -3" to "Very Likely: +3."

After each group completed two sessions of exercise and the post-questionnaire, we conducted a semi-structured focus group after collecting the photos from the smartphones. After recording and transcribing the focus group, we conducted qualitative data analysis by using an open-coding process followed by grouping based on the shared concept. Then, we tied similar concepts together. We performed the qualitative data analysis by following a published procedure in [42].

Results

Improving Group Awareness

LetsPic provides two types of awareness: activity-space level overall progress awareness and subgroup-level activity awareness. Participants commonly reported that they were keenly aware of their group and individual members' current status. For example, PA4 said, *"I could figure out where other members were and what I overlooked."* PA2 stated, *"When working with other members, I could easily figure out where and what the members captured."* Even participants used LetsPic intuitively in the way these two types of awareness benefited them. More precisely, PA4 stated, ''I used the gallery mode when I needed to check overall work progress [...] While taking photos, I used the radar view to check what others (collaborators) were doing if I needed to [...] To see recent activity of group members, I used the quick gallery view."

Furthermore, participants were satisfied with the current level of information that LetsPic provides to support awareness. For example, PC1 said, *"The information currently available on LetsPic is good enough to provide awareness because I knew where photos were taken and what others were up to."* A majority of participants commented that providing the locations of members on the map is "not necessary," as, explained by PF2, *"I could estimate others' location from the location of their most recent photos."* Some participants even expressed their concerns over having more detailed information on LetsPic. For example, PA2 thus expressed his concern, *"If there were more members in our group or LetsPic provided more*

		Mean (SD)		*Cohen's d*	*t-value*	*p-value*
		Camera App	**LetsPic**			
Groupware Usability (range: -2 ∼ 2)	**Explicit Communication**	-0.52 (0.77)	1.06 (0.48)	-2.45	-8.66	**0.00**
	Consequential Communication	-0.73 (0.63)	0.88 (0.65)	-2.52	-9.08	**0.00**
	Coordination of Action	-0.49 (0.77)	0.97 (0.51)	-2.23	-8.29	**0.00**
	Planning	-0.43 (0.75)	0.5 (0.93)	-1.11	-4.81	**0.00**
	Monitoring	-0.84 (0.73)	1.11 (0.67)	-2.79	-10.31	**0.00**
	Assistance	-0.51 (0.77)	0.97 (0.67)	-2.05	-7.32	**0.00**
	Protection	-0.53 (0.65)	0.43 (0.76)	-1.37	-4.81	**0.00**
Generic Usability (range: -3 ∼ 3)	**Usefulness**	-0.05 (0.85)	1.35 (0.62)	-1.88	-6.93	**0.00**
	Easy of Use	1.17 (1)	1.15 (0.96)	0.02	0.09	0.93
	Ease of Learning	2 (0.99)	1.99 (1.11)	0.01	0.04	0.97
	Satisfaction	0.72 (0.89)	1.71 (0.92)	-1.1	-4.81	**0.00**

Table 2. Result of two-tailed paired t-tests comparing usability between camera app and LetsPic for Site-survey study (α = 0.05).

detailed information, I would be too confused, or wouldn't be able to think straight [...] because of information overload."

Offering Opportunistic Collaboration

LetsPic offered three opportunistic photography experiences to participants. First, LetsPic offered an opportunity to capture unique photos by helping the participants navigate in the direction where members had not captured any photo yet, as explained by PB3: *"I could figure out the places that were less captured by viewing the density of markers on the map (at the gallery mode)."* Next, LetsPic offered an opportunity to iteratively improve the quality of each photo in the groups' photo collections. For example, AB1 explained, *"By viewing shared photos or photos taken by the same member, I could tell that some of the objects on the photos could be captured at different angles, so I went to the place and took photos at various different angles."* Last, LetsPic offered an opportunity to improve the diversity in groups' photo collections. For example, PC3 stated, *"I saw many ducks and geese (on the quick gallery view) so I captured other things like statues, rather than ducks and geese."*

Overall improved activity-space awareness significantly improved our participants' motivation for performing group work. PA3 said, *"This is not an individual activity but a group activity. When I saw updated photos in real time, I realized that others were working hard. And this helped me to think that I should also work hard."* Since photos are automatically shared, some participants compared their photos with those of others, and they wanted to take improved photos. PA4 commented, *"After I watched others' photos, I felt that I should take better photos than them. That's why I tried taking photos one more time, and to get the best shot, I also attempted to take a photo again."*

Enhancing Group Interactions

LetsPic provided enhanced group interactions. This app helped users develop more meaningful group interactions on the group messenger. The group messenger (KakaoTalk) played an important role in group interaction, as group members preferred to communicate with one another through the group messenger when they were not in close proximity. Participants reported that LetsPic enabled them to experience more meaningful interaction through the group messenger; as explained by PC3, *"LetsPic automatically shared photos with other group members, so we did not share photos using group messengers [...] so we could use messengers purely for communication [...] but when we used the camera app, we shared photos using messengers; there were too many photos between each message [...] often ignored."*

LetsPic helped to review the photos with other members more efficiently. For example, PA1 stated, *"(when using the ordinary camera app) with four or five people, we passed our devices to show photos but (when using LetsPic) without showing our device to others, without inconvenience, we could collectively select outstanding photos by using the Like feature, and [...] so we could communicate without much effort."* Interestingly, we found that the Like feature was used not only to review the captured photos, but also simply to encourage other members by giving Likes, as PA4 commented, *"Since we have a goal, I gave Likes whenever I viewed photos that align with the goal."*

In addition to the Like feature, the co-present mode in LetsPic also helped to review the photos with other members by shortening members' preparatory step before expressing their opinions. When using the ordinary camera app, as a preparatory step, members showed others the content displayed on their device or revealed the location of a photo on group messenger (e.g., third photo before last) to ensure everyone knows to which photo they are referring. For example, PA4 stated, *"To tell <Photo #1> is better, (when using the ordinary camera app) first of all I need to pass my device around to show <Photo #1>, But, when using co-present view, everyone could see <Photo #1> (by flipping the screen) and I could ask others' opinion by simply asking 'how about this' [...] If there were only couple of photos, it wouldn't matter, but we had a lots of photos. So the co-present definitely helps our group works more efficiently."*

Usability Results

To quantitatively measure the improvement on collaborative photography activities with LetsPic, we statistically compared groupware usability and generic usability metrics between LetsPic and the camera app (see Table 2). For groupware usability, our result shows significant improvements on seven major activities in collaboration when using LetsPic compared to when using the camera app. This result also supports our qualitative results showing that LetsPic 1) enhances group interactions, 2) improves group awareness, and 3) offers opportunistic collaboration. In particular, we found significant increase in two types

of communication (i.e., explicit and consequential communication), supporting that LetsPic enhanced group interactions as shown in our qualitative results–awareness enriches the two types of communication [17, 33]. While the increase in the two types of communications shows indirect evidence for the improvement of group awareness when using LetsPic, the significant increase in Monitoring shows direct evidence that participants maintained a greater amount of awareness during collaborative photography activities when using LetsPic compared to when using the camera app. Last, our qualitative result showed an increase in Coordination of Action, Assistance, and Planning that supports the qualitative result that LetsPic offers opportunistic collaboration. For generic usability, our result shows significant increases in usefulness and satisfaction, but there was no significant difference in ease of use and ease of learning. This result is reasonable since the camera app is a familiar app and our participants used LetsPic for the first time after receiving brief instructions.

STUDY 2: THEME PARK

Participants and Procedure

We evaluated the user experience with LetsPic in social contexts by conducting a user study at EverLand, the largest theme park in Korea. For this study, we recruited five social groups consisting of four to seven members through on-line bulletin boards at five universities. In total, 24 participants were recruited. The average age of our participants was 21.0 (SD = 3.3) years. Nine were female and fifteen were male. Seventeen were university students. For compensation, we offered USD 50 to cover transportation costs and the entrance fee. Prior to our study, fourteen participants had visited the same theme park before. At least one day before our experiment, we arranged a meeting with the group and explained our study and the LetsPic app. During the meeting, participants installed LetsPic on their smartphones and were asked to use the LetsPic app with their group members at the theme park. Note that only instructions related to LetsPic usage were given to participants. Each group visited the theme park on different dates. After a group left the theme park, we had focus group interviews with the participants. The interviews were recorded and then transcribed. For qualitative data analysis, we conducted open coding in which we explored shared concepts and clustered them into similar categories [42]. Similar to the site-survey study, participants also completed a groupware questionnaire [16] and generic usability questionnaire [29]. In addition, we also conducted a follow-up survey after the group focus interview. We corroborated the results with GPS log data and photos, as well as the follow-up survey.

Results

Understanding Photography Behaviors

Beside going for rides, participants spent most of their time taking photos, as PC2 said, *"We mainly took a lot of photos."* Our participants stated that photo taking is very important, and it is considered as their common routine for social group travel or visiting. Our participants commonly cited the saying, *"The only thing that remains is pictures."* Unlike the site survey scenario, most photos were about the group members themselves, and the number of other types of photos (landscape, objects, and animals) was relatively small. The average number of taken photos per person was M=123.8 (SD = 130.7, Min = 27, Max = 542). When taking photos, many participants (n=16) simultaneously used a few camera apps equipped with specialized filters and stickers such as Candy Camera [31] and Camera360 [32]. LetsPic allowed them to easily import those photos to the group's gallery view.

Enhancing Group Awareness

Participants enjoyed undertaking several well-known rides together, but because of different interests, they sometimes divided into subgroups, as well explained by CP1, *"Sometimes we went on the same ride but often divided to take different rides. <Member #1> and <Member #2> went on <Ride #1> while the others went for <Ride #2>. [...] and sometimes some of us didn't take <Ride #3> and spent time alone. <Member #2> was afraid to take <Ride #3> so waited for us at the cafe."*

Participants reported that they were keenly aware of other members or other subgroups when divided. For example, PB2 says *"When divided, by seeing photos and dots (makers) on the map whenever they took photos, we could expect what people were doing where."* Photos from one subgroup allowed other subgroups to know what other places looked like. This awareness encouraged them to explore unvisited places and helped them to make decisions about which places to visit. For example, PA4 *"The theme park was too large, so we couldn't know where we had been, but by looking at the map, we saw no markers on the other side of a road while we were walking along the road at the time, [...] so we crossed the road and [...]."* Furthermore, our participants sometimes intentionally take photos simply to let other members know whether they are located. This selective sharing of location was mainly used to help members to explicitly provide group awareness.

LetsPic helped participants to manage activity time more efficiently as a group by allowing them to view others' status through photos and dots (markers) on the map. Participants commented that they considered efficient time management as an important task, to enable them to experience as much as possible at the theme park. For example, PC5 *"Some of us took other rides [...] we organized our activity according to others' group activity. When another group took <Ride #1>, I left the waiting queue for <Ride #2> and joined the other group."* Participants were also keenly aware of how to improve efficiency in time management and group coordination through LetsPic. For example, one of the groups reported that [EP3] *"When we were separated, we often took photos without any purpose other than to inform another group of our location, to inform the other group could know what our group was doing."*

Group awareness encouraged our participants to take more photos. Our participants commented that the major reason was because automatic sharing lessened the burden of sharing, as PA1 said *"We don't usually take photos. But today we took many because with LetsPic we don't need to manually share with others [...] With the default camera whoever takes photos, they have to share with others. That's frustrating and sometimes time consuming if there are many."* DP6 contrasted how LetsPic changed their overall photo taking experiences, by saying, *"I loved the automatic photo sharing feature. [...] We capture too many and generally we don't share, we don't see. It takes too much time especially sharing with KakaoTalk*

		Mean (SD)		*Cohen's d*	*t-value*	*df*	*p-value*
		Site survey (n=30)	Theme park (n=24)				
Generic Usability (range: -3 ∼ 3)	Usefulness	1.35 (0.62)	0.56 (1.34)	0.8	2.66	30.93	**0.01**
	Easy of Use	1.15 (0.96)	0.48 (1.43)	0.57	1.95	38.76	0.05
	Ease of Learning	1.99 (1.11)	1.14 (1.12)	0.78	2.81	52	**0.01**
	Satisfaction	1.71 (0.92)	0.82 (1.27)	0.84	3.00	52	**0.00**

Table 3. Result of two-tailed independent t-test comparing generic usability of LetsPic for Site-survey study and Theme-park study (α = 0.05).

(messenger) [...] Every one shared their photos when they got home or in a WiFi zone because of the data cost to send lots of photos without WiFi networks. So if some share their photos it is generally assumed that they arrived home."

Enhancing Opportunistic Collaboration

Several themes of opportunistic collaboration emerged. Our participants iteratively improved the quality of photos in situ. All groups reported that LetsPic helped them to capture some scenes by iteratively performing capture-review quickly, as explained by PC2, *"While maintaining our pose, we could review immediately just after a photo was taken through an enlarged photo (at the quick gallery view). We could immediately check whether we had bad focusing, unfavorable facial expressions, or [...], and if so, we took again, paused, and checked again (repeated)."* Moreover, our participants used LetsPic as a tool for helping each other. For example, according to PC3 *"When anyone saw nice photos taken by others, I asked others to use the view finder to view me taking a certain pose and at the same time referring to the photo on a viewfinder (quick gallery view) [...] It is annoying when using camera app. Generally we need to use two cameras side by side, referring a photo at one camera and capturing and checking from another."*

Enhancing Group Interactions

LetsPic helped to have more meaningful face-to-face interactions with other members as well explained by PC1, *"We talked a lot with others nearby [...] Because even when separated, we could know what others were doing, so we didn't need to use other means such as talk using the messenger to ask what they were up to or to reply."* The Like feature also enhanced social group interactions through simple expression that group members' like their photos. Participants mainly pressed Like as indicated by PE5 *"when I or others in the photos look nice."* Interestingly, some participants reported that the Like feature helped them to implicitly judge whether photos can be shared with other people outside the group. For example, DP6 mentioned that *"I uploaded a photo on Facebook if the number of Likes on the photo is one less than the number of people in the photos or more. [...] for example, (showing one of their group selfies with all five group members) if I want to share this photo on Facebook or upload it as a profile photo, I need to ask all four except me. But if a friend did Like it, I assumed I can upload without asking him. If all friends did, Like count is four, and so I upload any photos with four Like without asking friends."*

Although many of our participants used multiple camera apps simultaneously, LetsPic facilitated photo sharing across group members. We found that these camera apps were mostly used to take personal/group selfies. Our participants personally kept most photos themselves, but group selfies were often immediately shared with LetsPic. When making sharing decisions, our participants mentioned that the most important criterion for sharing was to see what their own faces looked like. Privacy was not a serious concern, partly because personal selfies were not even considered for sharing. PE3 commented, *"With the camera app, I mainly took my selfies. [...] I didn't upload my selfies on LetsPic because I found no reason to do so. If I took group selfies, I uploaded on LetsPic if I look nice on the selfies."* We also confirmed through examining photos on LetsPic that personal selfies were taken only in the beginning, and group selfies were mainly taken subsequently. In addition, most of the photos that were taken by camera app were personal selfies.

Usability Comparisons

To quantitatively compare how activity-space awareness in work and social contexts (site-survey vs. theme park) differs, we statistically compared the score of the groupware usability questionnaire and generic usability questionnaire between the site-survey study (LetsPic condition only) and theme-park study. For groupware usability, our result shows no statistical difference between the site-survey study (overall M = 0.84, SD = 0.27) and theme-park study (overall M = 0.86, SD = 0.22). Namely, a similar level of support was provided for the seven major activities of collaboration in the site-survey study and theme-park study. For generic usability, our result shows a significant decrease in usefulness, ease of learning, and satisfaction when using LetsPic in the site-survey study compared to when using LetsPic in the theme-park study. In addition, it can be considered that ease of use is also increased when using LetsPic in the site-survey study compared to when using LetsPic in the theme-park study since the effect size (i.e., Cohen's d) is high and the p-value is marginally significant.

DISCUSSION AND CONCLUSION

We investigated collaborative photoware design for in-situ collaborative photography by supporting extended co-located social interactions. Towards this goal, we developed LetsPic and performed two case studies on work and social contexts, namely the site survey and theme park tour scenarios. These cases have different purposes: the site survey aimed to collaboratively collect quality photos in a given area, whereas in the theme park tour, sightseeing and rides were the main purpose, and photo taking was a secondary task–collecting quality photos is critical in social contexts as well. LetsPic supports two levels of activity-space awareness, namely the global awareness with the gallery mode, and localized awareness with the radar view. Our results showed that activity-space awareness was used differently: in the site survey, the gallery and radar views were mainly used for group work coordination, whereas in the theme park tour, the gallery view was mainly used for tour planning and affective sharing.

In addition, we observed social-learning-based collaborative photography in both cases, where members view shared photos and learn what was captured, and how they were taken. Social learning greatly improved user motivation to contribute quality photos and facilitated collaborative behaviors. In the following, we discuss the practical design implications of these findings, namely (1) delivering activity-space awareness, (2) facilitating social learning in collaborative photography, (3) scalable group support, (4) technical concerns of LetsPic, and (5) generalizability and limitations.

Delivering Activity-space Awareness

LetsPic seamlessly supports the entire process of "collaborative photowork," including capturing, sharing, monitoring, and reviewing. This seamless integration of the entire process minimized context switching costs while on the move, and thus, it provides shared resources for moment-to-moment collaboration among participants. In our formative study, we found that when instant messengers were used as photoware participants experienced overload because of the number of photos, and were disturbed by frequent interruptions. Our results concur with those of the work of Fischer et al. on mobile notification management with collaborative photography [11]; i.e., notification was often deliberately ignored while taking photos and talking with a collaborator. LetsPic supports two levels of activity-space awareness since subgroup formation and collaboration in the subgroup occur opportunistically. The cohesion and dispersion of a subgroup in our study is similar to the micro-rhythms observed in Mobiphos [6].

LetsPic delivered activity-space awareness with an interactive map due to mobility of users over a large physical space. To support two levels of activity-space awareness, we embedded two interactive maps on gallery mode and radar view, respectively. The map on gallery mode is designed to support global awareness. We intentionally designed the gallery mode as an initial landing page since it is well known that a natural breaking point is less prone to interfere with or disrupt one's task [30]. The map on a radar view is designed to support localized awareness. We followed the "peephole" design concept [8], which provides only a limited view of a larger information space, since providing too much information may negatively influence overall work performance [45]. LetsPic used colored pins to display geo-tagged photos over an interactive map. Marker visualization should carefully consider task types and coordination requirements. Beyond awareness support, interactive maps can be leveraged to guide personal/group behaviors. For example, on a field trip, we can highlight must-visit places, or provide a task of location-based stamp collection.

Facilitating Social Learning in Collaborative Photography

Extended co-located social interaction enabled social learning, which greatly encouraged our participants to contribute quality photos and also facilitated collaborative behaviors. In both scenarios, our participants learned from others' good exemplary photos or notable sites to visit. Although LetsPic implicitly supported social learning, we can consider a more explicit design that can facilitate social learning. For example, we can use liked photos on the gallery view. Those members who are good at photography may receive professional badges, which can be displayed on the map. As suggested in earlier work [3], we can leverage meta-data included in the photos (e.g., location, angles) to assist in taking improved photos. In the social contexts, social learning led to new forms of collaborative photography: two or more people co-create a photo. Supporting real-time and in-situ collaboration not only requires timely information sharing but also novel interaction methods. Exploring these issues would be an interesting avenue for future work.

Scalable Group Support

Our work is suitable for small groups since it is less common for large groups to work synchronously [17]. Scalability issues may arise if it is used by a large group of users. Despite various filtering options (e.g., filtering by photographers), information overload may occur. One way of handling a large group is to explicitly form sub-groups/channels. Another solution is to leverage generalized fisheye views [15] that balance local detail and a global context; e.g., nearby photos from a user's current location are fully shown, but photos of distant scenes are aggregated/abstracted.

Technical Concerns of LetsPic

Our exit interviews revealed several technical concerns of LetsPic. In our theme park study, several participants mentioned the battery consumption of LetsPic. In fact, frequent GPS tracking and automatic sharing are the major sources of battery consumption. We can introduce context-aware adaptive GPS sampling [35] and efficient data compression/transfer methods [9] to lower the battery consumption. Another major concern is related to the lack of camera features such as specialized camera filters, selfie buttons, convenient importing/exporting, and video recording support.

Generalizability and Limitations

Our results could be applicable to other domains of in-situ collaborative work where tasks involve exploration and opportunistic collaboration over a large physical space using mobile devices, for example, citizen science (e.g., locating invasive plants), mobile augmented reality games (e.g., Pokemon Go and Human Pacman), community policing (e.g., group patrolling and sharing captured events [36]), and disaster relief and emergency operations (e.g., surveying recovery status and coordinating rescue operations). Citizen science may involve in-situ collaboration for data collection over a large space where participants use their own mobile devices [49]. By embedding a view with an interactive map showing where data has been collected, similar to our galley mode, participants could naturally coordinate their actions in situ. Another example is mobile augmented reality games that often require users to explore a large physical space [2]; activity-space awareness can be applicable to game design to promote opportunistic exploration or collaboration with other team members. Nonetheless the generalizability of our findings is limited due to small scale field trials. Further studies on various group activities over different sites and possibly with different cultures should be performed to generalize the findings.

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