Teaching the Design of Ubiquitous Computing Systems

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Abstract

Interaction design for a relatively new paradigm like ubiquitous computing requires a deep understanding of everyday work practices and environments. To design such systems requires that students use techniques like ethnographic methods to explore work practices, technology probes, physical model building and role-play to produce, test and demonstrate the designed artefacts in a realistic way. In this report, we discuss our approach to designing learning activities that provide a repertoire of HCI techniques to support the design of ubiquitous computing systems, and show the outcomes of projects undertaken by students in the form of work practices and requirements identified by them, and their design solutions. In these projects students undertook an ethnographic investigation into their own work practices to design ubiquitous support for student group work. We also undertake an evaluation of the teaching approach.

Keywords

Ethnography, technology probes, physical model building, role-play, contextual scenario, ubiquitous computing, CSCW.

INTRODUCTION

Ubiquitous computing is a relatively new design paradigm that requires changes to the way we teach interaction design. It involves the integration of computer technology with everyday work practices and environments. It requires an understanding of what people do, individually or in groups, wherever they choose or need to do so. This requires the use of ethnographic methods, rather than the more traditional systems analysis methods which concentrate on the way that individuals perform tasks with a conventional system involving a screen, keyboard and mouse (Dourish, 2004). Similarly, in testing and demonstrating these designs, the interaction, which is often opportunistic and may involve mobile or embedded systems, must be simulated in some way, e.g. through role-play. To teach the design of these systems, one must create an environment where the students can experiment with these techniques in a realistic way.

This report is based on the masters level subject Issues in the Design of Human-Computer Interfaces (IDHCI), where we have attempted to do this by getting students to design ubiquitous computing support for their own group project work. In this report we discuss our approach to designing learning activities which would provide a repertoire of HCI techniques to support the design of ubiquitous computing systems, show the outcomes of the projects in the form of work practices identified by the students, the requirements that they identified and their design solutions and undertake an evaluation of the teaching approach.

Background

We have a long-term involvement in the design of learning activities in the HCI areas of CSCW and computer supported collaborative learning (CSCL) (e.g. Collings et al, 1997, Collings and Pearce, 2002). Our students are required to do considerable group work in order to learn how to use a team approach to the analysis, design and implementation of computer-based systems – a generic skill seen as important by employers and ourselves. One way in which we have involved students is by asking them to articulate their own requirements through Masters level subjects. Each year we design a new version of one of several HCI subjects that are offered at this advanced level. Through these subjects students have designed, used and/or evaluated synchronous and asynchronous workspaces (Walker et al 1998), face-to-face versus online meetings, speech input to systems (Collings et al, 2002), and similar support for changing work practices.

The Participants

There were 20 students enrolled in the subject distributed in groups of five. The students' backgrounds and experiences varied widely, with a mixture of full time and part time students. Hence some lacked any experience in the workplace and others had already started their profession in IT. The majority of the students were international or non-English-speaking background students. They brought with them quite differing styles of learning. For a few of them this was their first semester at an Australian University.

Choice of Project

In the limited time available, a manageable ethnographic research task needed to be identified. This was the reason for choosing to design ubiquitous support for student group work. There might be issues arising from the students' role as designer-participant. But in this case, this had the advantage that the subjects for the ethnographic study were readily available, and the work domain was familiar. The other students of the class (from other groups) in fact were potential and typical users of the systems groups designed. Their active involvement essentially contributed in the process of iterative user-centered design.

Resources and Support Services

The student groups received a number of documents: a reading brick with a number of background reading materials including examples about ubiquitous computing systems, information on the subject structure and assessment (three group assignments, one individual reflection); and templates for observation sheets and individual diaries.

For the 15-week period allocated for the subject, students met for one 3-hour block every week on campus (with the exception of the two week mid-semester break in weeks 8 and 9 and a public holiday in week 12). The first hour was treated as the lecture time with the rest of the time set aside for group discussions, tutorial exercises, presentations, progress reports and design review sessions. The teaching team and guest lecturers (experts in the field of study) gave briefing-style lectures on issues related to ubiquitous computing, examples of such systems, work practices, ethnography, analysis and design techniques and frameworks, group cohesion and report writing, linking the project back to theoretical frameworks.

DESIGN TECHNIQUES TAUGHT

We now describe the repertoire of design techniques that we offered the students. We first describe the design methodology. Then we describe what each technique is, why each technique is relevant and then show how it was used.

Design Methodology

The nature of ubiquitous computing makes design of ubiquitous computing systems difficult. There is not a well-defined set of tasks involving a well-defined user group for which a well-defined set of requirements can be derived. Instead it is a form of speculative design, where the users are discretionary users, which means that they can choose whether or not to use the system or technology, and also how they will use it.

The design method can be thought of as an iterative design methodology incorporating ethnographic investigations. It is roughly as follows:

1. Identify a group of 'typical' users from the target group.
2. Observe how they work and identify their work practices, using ethnographic methods. Develop a set of requirements by identifying areas in which there is a need for technological assistance, usually because there are 'gaps' where there are things that they would like to do but cannot, or where existing ways of doing things are awkward or difficult.
3. Develop potential solutions, testing them using scenarios based on the observations of the work of the group.

Ethnographic Study- Identifying Work Practices

System design is frequently work design. In order to undertake innovative ways of designing work, "it is vital that designers understand the work setting as a socially organized setting as a preliminary to design" (Hughes et al. 1995, p64). Ethnography can be used as a means to uncover the 'real world' character of work for systems design, especially in new areas like ubiquitous computing.

In this subject, our target user group was university students. Our 'typical' users were the IDHCI students. The students participated in the project in groups of five. It was decided that students would self-observe their own work to get an insider's view. The study differed from usual ethnographic studies in that all group members are 'ethnographers' rather than there being one or more 'independent' observers. The ethnographic research was done in the following way:

- Each group of students was asked to prepare a class presentation on a topic in ubiquitous computing (Assignment 1) and at the same time observe how they carried out this work, recording their activities (both formal and informal communication) through diaries and observation sheets (Assignment 2 – work practices). The students were encouraged to use a wide range of available technology. Some of these technologies were possibly unfamiliar to the students (e.g. an asynchronous discussion tool) and worked as 'technology probes'. (Hutchinson et al, 1993)
- Two members of the group were designated as 'observers' in each face-to-face meeting. The observers compared their notes to produce a meeting summary. The observers also participated in the meetings as in action research. Everyone played the role of observer in turn.

Data Analysis Techniques

The students needed some techniques to analyse the data gathered to identify key activity patterns. The idea was to spark creativity, i.e. not encourage a solely deductive process. We added the following range of techniques to the students' repertoire through lectures and tutorials.

- Locales Framework
- Work practices categorisation

Locales Framework

The Locales Framework (Fitzpatrick, 1998*)* was developed as an approach that allows for construction of shared abstractions for both understanding and designing for collaborative work. In this framework the locale can be seen as the set of all the different places participants work from and the means of communication between them. In virtual locales multiple physical locations are connected in some way, providing the site and means for the social world to collaborate. The framework is based on five aspects that characterise work from different perspectives: Locale foundations, Mutuality, Individual view over multiple locales, Interaction trajectories, and Civic structures.

The framework can be used as a starting point to help explore the key elements in a collaborative work situation (in this case student group work). The framework aspects can be used to structure the data gathered through any ethnographic study. Further, in design, this framework can be used to identify where features can be added to enhance existing locales, or to help identify where new locales can be created in order to support the work of a group.

Work Practices Categorisation

The activities of the group can be thought of as consisting of:

- Substantive (real) work, which is the performance of tasks directly related to the goals for the work; and
- Articulation work, which is best described as "the work needed to get the work done" (Kuutti et al 1996, p183). Articulation work includes project management work, group maintenance work and ensuring that the communication mechanisms actually work (e.g. sending an SMS to someone to ensure that they reply to an e-mail message).

Understanding User Requirements

The question was one of how to use ethnographic data to inform design. The process was both creative and deductive. This was done in three stages:

1. Based on their work practices, the students were asked to identify areas of group work where technology dictated or distorted their work practices and find any gaps between their expectations and desired technological assistance. This was intended to spark a creative look at the problem. Based on the identified 'holes' in existing technology the groups came up with a list of requirements for ubiquitous computing support for student group work.

2. Then a focus group was used to synthesize their ideas about ubiquitous support and link their needs based on their findings of their current work practices. The requirements were listed in terms of their perceived importance among the individuals who categorised them to identify key areas of support.
3. Each group then developed their own set of requirements based on the focus group and their own interests. These were presented to the class in Week 10, and were later refined through discussion with staff members.

Design

During the design stage, each group narrowed down their list of requirements in a subjective way to make it distinct from those of other groups. This divergence was encouraged for teaching purposes so that a diversity of ideas was explored. The groups were encouraged to develop imaginative solutions that might reflect future technologies, rather than be limited by existing technologies. Cost was not seen as an issue, since something expensive now may well be very cheap in the future. Thus technical and economic feasibility were not seen as issues, but organisational feasibility (would it work for the group) was.

Testing Techniques

Three techniques were introduced in the subject to assist in testing the designs:

The Bellotti Framework

Conventional human-computer interfaces such as the graphical user interface (GUI) are not always appropriate in a ubiquitous computing environment where the device may be invisible in use. Other available interaction techniques include handwriting, speech, touch, and eye gaze detection. Bellotti *et al*. (2002, p419) ask five questions (address, attention, action, alignment, accident) that can be used to test design solutions for use in ubiquitous computing environments.

Physical Model Building

In order to understand and design for interactions in CSCW and ubiquitous computing environments, it is useful to develop and test models of the proposed artefacts. Physical representations of the artefacts provide an opportunity to look at the uses of the artefacts in a three-dimensional view rather than screen-based representations (e.g. storyboarding). Physical representations of ethnographic data can be used to develop design understandings. "Physical, durable models go a long way in exploring and obtaining insights into the interaction and exchange between collaborating people" (Campbell et al, 2003). Students built physical mockups of the artefacts using cardboard and paper.

Role-Playing

Role-playing based on contextual scenarios is a technique that can be used to assist in the exploration of design developed from an ethnographic study of current work practices. Contextual scenarios reflect fragments of use, where the actors act-out with 'props' (e.g. the cardboard mockups) and can answer how and when and why the activity took place (Gaver et al 2000, Howard et al 2002, p2).

Role-play is also seen as an experiential learning tool and can promote learning through active participation. The role-play exercise here was done by the student designers rather than by the professional actors preferred by Howard et al (2002). The students needed to tell their stories. It served as an effective way of understanding, communicating and evaluating design ideas.

Using a participative and iterative design development approach, students tested and further developed artefacts for ubiquitous support for student group work as follows:

- Firstly, students used the Bellotti framework to see if the cardboard prop really supported the interaction.
- Secondly, students role-played with cardboard mock-ups for the contextual scenarios of use in their 'work' context and tested the mock-ups to see how they could use them to support their work.
- Lastly, students incorporated the feedback from design review sessions with staff and students to improve the design. Students had intensive review sessions with staff and other students both in class and between sessions and informal review sessions within their own group.

RESULTS

Student Work Practices

The key feature of the work practices reported by the students is that their work is fragmented in both time and space. They work in multiple locations e.g. home or work and on campus for multiple projects (subjects). They perform different tasks in different environments (i.e. work and study) within externally defined time frames.

Locales
The students identified two types of locale:

Distributed Locale: The students worked from home and/or work. They performed their tasks through the use of computers, email, telephones, mobile phones (SMS), the Internet, an asynchronous discussion tool (e.g. WebCT, Yahoo Groups), IDHCI website, printers and online video conferencing (e.g. Yahoo Messenger). Interaction in any distributed locale was limited by the lack of richness of interaction (text only or voice only) using available technology

On Campus Locale: The groups (especially the groups with only full-time students) met face to face in a suitable meeting room (e.g. in the library). The on-campus locale was identified as being technologically poor (no computer support in library meeting rooms, and the labs were too noisy and wrongly organised to be usable for meetings). Students were unable to review or edit their work using a computer, which forced them to resort to pen and paper.

Categorisation of Work
The purpose of the categorisation was to identify common patterns of activity which formed an important part of group work. Firstly, the tasks related to group work (i.e. task management, group maintenance, communication, travel etc) can be categorised by separating group work from individual work. Secondly, group work and individual work both can be categorised into substantive and articulation work.

Substantive (real) work identified: The actual work for the project involved multiple iterations of a combination of researching, writing, and presenting findings to the class. For the second half of the semester, the groups engaged in interaction design and built physical models to test the designed artefacts.

Articulation work identified: Two major things were identified within their work practices in terms of articulation work:

- Coordinating and managing meetings: For activities related to meetings (e.g. arranging meetings, keeping minutes, follow-ups, documentation reviews) the groups relied on email or mobile phone (e.g. SMS) for coordination.

- Distributing documents: The students worked on their project from different locations, they shared work through email attachments, or printed or scanned documents during face-to-face meetings.

- Other:
    - Distractions - Distractions are any form of interruption by a person, thing or event that prevents the group or individual from proceeding with an allocated task. For example, a car breaking down on the way to attending a meeting, private phone calls, noise etc.
    - Travel - Travel is any form of travel undertaken by group members to attend meetings. For example, group members who were reliant on public transport needed access both to bus timetables and to information about specific services (e.g. whether they were early or late or had already passed a specific stop).

Requirements for Ubiquitous Computing for Student Group Work

Based on students' ethnographic investigations, students' requirements were generally identified as:

Document sharing: The groups needed to share documents anytime, anywhere among themselves with version control.

Enhance face-to-face meetings: Students needed support during face-to-face meetings to do both articulation work (e.g. scanning documents such as research papers) and substantive work (e.g. editing documents by participants).

Enhance virtual meetings: Ability to hold a meeting remotely was an obvious requirement for the student groups. Interesting enhancement to these meetings were proposed:

- The need to flag important parts of the meeting, as students needed some mechanism to capture the design decisions made at the meeting and later write-up minutes for the meeting.
- Have private conversations while in a virtual meeting.
- Ways to enhance their experience of video conferencing by being able to follow body gestures.
- Ability to reach or locate other group members while waiting for their attendance at a scheduled meeting to determine if they are late or not attending at all.

Visual modelling: In both distributed and face-to-face locales, students wanted to convey design ideas (both two-dimensional drawings and three-dimensional representations) in a visual manner, so that other members could comment on and change the design immediately during the meeting. Shared whiteboard space or manipulation of a hologram using hand gestures was proposed. The ability to draw rich pictures from a narrative was seen as desirable.

Enhance communication: Students wanted the ability to communicate with each other while they are on the move.

Managing time: Students preferred help in organizing activities by reminders for meetings, workflow alerts for some action, personalized bus timetables etc.

Design Solutions

Ubiquitous computing is characterised as having two dimensions (Lyytinen and Yoo, 2002):

- Mobile computing, which is the ability to work from any place and at any time; and
- Pervasive computing, in which computing resources are spread through the user's environment, often in the form of sensors and other semi-autonomous devices.

Ubiquitous computing solutions contain elements of both of these, but in some one is more important than the other. Three features of ubiquitous computing solutions are also important (Abowd et al 2000):

- Context awareness, in which a device may need to know where it is, who is using it, and/or other information about its surroundings (e.g. temperature); and
- The need for different forms of interaction (in addition to keyboard and screen), appropriate to the type of device and the context of use. The Bellotti framework (Bellotti et al, 2002) was introduced to assist students in the design and evaluation of such interfaces.
- Capture of live experience, (e.g. proceedings of a meeting) and providing flexible access to those experiences later on.

The groups designed ubiquitous artefacts to support the areas they identified as needing better technological assistance. They were based on their own work practices and each group was encouraged to emphasise different aspects of their requirements. Some of the solutions are ideas for new technology, while others are innovative ways of using existing technology. Most incorporated context awareness in some form, and most used a variety of interaction modes (e.g. speech, touch, eye gaze). Three of the design solutions emphasised the mobile dimension, supporting different forms of video-conferencing as a central feature (for details see Alam et al 2004). The four designs are now briefly described.

Roaming Office is built around a central data store which can be accessed through a variety of devices. The group concentrated on two devices:

1. The Access Point, which is conceived as being a bit like a laptop computer but with added functionality, and which had the full functionality needed for the system.
2. The Cray 3000, which is a wearable device about the size of a wrist watch, with limited functionality, being designed mainly for articulation work.

The design focused on two distinct problems: manipulation of three-dimensional images, in the form of holograms; and locating and contacting group members, e.g. someone who had not arrived at a meeting. At the demonstration,

the group used a wireframe shape with control points to illustrate the manipulation of the holograms, but envisaged that this might actually be done by touching the hologram itself, the finger movements indicating the required changes in shape. Different users at different locations would all have copies of the hologram which they could manipulate.

GroupSys addressed the problem of being tied to a single workstation while videoconferencing. It features very thin, flexible A4 sized screens which can be attached to any surface. These contain sensors to detect both the presence of a user (who initially activates the screen and identifies themselves through a thumb print) and whether they are looking at the screen (through eye-gaze detection). There can be many of these screens in the one house. Additional sensors can be located at convenient places. Other devices, e.g. a TV set, can be connected to the system and used to display messages. Thus a user can move from room to room in their house, and perform other tasks, while still participating in the videoconferencing activity.

The Mobile Team Assistant was built around a set of small portable devices like PDAs. These supported remote conferencing through video and audio streams and a facility for sending messages between participants. The key feature of this system was support for documenting what happened in meetings through the ability to "bookmark" important passages in the meeting. These bookmarks could then be used to locate the relevant video, audio and messages to compile minutes of meetings and design rationales.

The fourth design solution, the *Smart Table*, had more pervasive elements. The focus of this solution was the enhancement of the technology-poor on-campus meeting rooms. The concept was of a Smart Room, in which the group could meet. The room had sensors, to detect who was there. The central feature of the room was a Smart Table, on which group members could lay out paper documents that they had prepared outside of meeting times. These were seen as being sections of some larger document to be complied at the meeting. These documents could be scanned in a specified order (controlled by a touch interface) and incorporated into the larger document, which could then be edited, formatted and printed. An additional feature, attached to the Smart Table, was the Smart Book, a device that looked and acted like a book, with pages (actually very thin, double-sided displays) that could be turned over. This could be used to download content from the university library. This could be then read (as a book), or quotations extracted for use in the document being developed.

The Smart Table contained a mobile element, in that it was envisaged that it could be folded up and moved, and that a group member in a different location could interact with the group through another Smart Table at that location. One idea was that members at a different location might be represented by a hologram.

EVALUATION

Evaluating this style of teaching and experiential learning is difficult. Student evaluations vary according to how engaged they were in the subject and are partly dependent on the dynamics of the specific group and group cohesion in general.

From the Perspective of Students

The teaching team undertook an evaluation at the end of semester in class in week 15. The survey was conducted by the Center for Enhancement of Learning, Teaching and Scholarship (CELTS), an independent body of the University. There was a 90% return (18 responses).

Overall the students rated the subject as 'Good'. One comment was:

> *It was one of the most enjoyable classes.*

In terms of the original learning outcomes of the subject, students made the following comments about what were the best aspects of the subject:

> *Overall good subject to learn about ethnography, ubiquitous [computing] and role-play.*
> *Ethnographic study of group was interesting.*
> *Ability to be creative in thinking design concepts never thought before.*
> *Innovative ideas about designing and HCI.*
> *Learned about new technology ubiquitous computing.*

From the comments above it is clear that the students enjoyed their participation in ubiquitous computing, ethnography and role-play. 67% responded that they have learned a lot in this subject. 90% of the students agreed that they have extended their ability to be creative in their work, which was a major goal of this whole exercise.

Students formed a conceptual framework for designing and prototyping mockups with emerging technology. As they said in their individual reflections and the survey, they learned new techniques like ethnography and role-play with mock-ups and experienced innovative design techniques.

Students also gained transferable generic skills in CSCW. The following set of comments highlights this:

The subject supports you to do group work.
[The subject had an] environment good for communication in class.
[Students] improved presentation skills and improved confidence.

Students learned to appreciate the need for support in performing articulation work in cooperative work. This was not known by them in advance, but observed through practice. They also learned to appreciate that designing for CSCW is seen to be solving a 'wicked' problem (Fitzpatrick, 1998, pp122) in which there is no single solution, you can come up with good designs by improving them through 'use'.

The complexity of the project was raised by a couple of groups with many students commenting that they did not understand the big picture till the end. This is not at all unusual with experiential learning, the result of which is often realised over an extended period, possibly months or even years.

In general, only 10% disagreed that the assessment tasks developed an understanding of the material. Students generally agreed (72%) that they learned to be responsible for their own learning. This is interesting because, for some of the international students, this was their first experience in an exploratory design project of this nature. This also reflects that there is a high degree of constructive alignment between the objectives of the subject, the learning activities and assessments of the learning.

From the Perspective of the Teaching Team

Students' prior learning experiences were taken into consideration in designing the subject. It was a fundamental assumption that students had knowledge of iterative design, Web and GUI interface design, quality management, project management, and rich pictures. The idea was to extend this repertoire of design techniques and add appropriate and relevant techniques like: ethnography, understanding work practices, technology probes, Locales Framework, creative and deductive design processes, focus groups, the Bellotti Framework, role-play and physical model building (cardboard mockups). The personal and distributed nature of ubiquitous problems suggests that this set of interaction design techniques is relevant here. The students are expected to learn how to make discretionary use of these tools to suit a particular design situation. This is a meta-level outcome of the subject.

Students were encouraged to conceptualise key activities from multiple perspectives. They played both the roles of observer and participant in the ethnographic investigation of their work practices. They were encouraged to use both deductive and creative processes in coming up with the list of requirements and in designing cardboard props to support their work practices. The Locales Framework, work categorization as substantive or articulation work, and rich pictures gave them multiple views of the same ethnographic data. At the end, students prepared an individual reflection on their design as a further perspective.

One major problem observed was the lack of experience in role-playing. Thus the level of interaction and level of participation in role-playing the contextual scenarios with cardboard props was low. It is clear that more time needed to be spent in training students how to role-play by giving them examples and opportunities to develop their skills. This is an area that needs to be addressed for any further use of role-play in system testing.

At times, the students found some difficulty in coming to terms with the parameters within which they were asked to work. This was particularly the case in developing their final designs. One group moved away from a touch interface to a far less appropriate speech interface because they felt that speech was more appropriate to a ubiquitous computing device. Another, due to the influence of one group member, concentrated on technical aspects of their solution (which was not required) at the expense of user interaction. The consequence was that some of the solutions given in the final presentation were far less interesting and imaginative than the initial ideas.

The subject was designed in such a way that students immersed themselves in a real-life ethnographic investigation. There was a high level of uncertainty. The students had to interpret and adapt their theoretical knowledge to complete the task and this provided a challenge to them. This required and was given a high degree of peer and tutor support through review sessions and reflections. All participants benefited from the work of each group. Each group presented progress reports and the results of their work to the class as a whole, at intervals, during the semester. The way that each group gave useful feedback to every other group helped to improve their designs However, the level of competition among the student groups meant that not all design ideas were shared. For example some groups deliberately held back a few of their ideas in the design review sessions and the focus group.

The overall pass rate for the subject was 100% with each student successfully meeting the assessment and passing requirements of the subject as set out in the subject outline. The pass rate is higher than the average pass rate (75%) for Masters of Information Technology subjects offered from 1998–2002. This is attributed to a higher staff to student ratio than normal as it was a research method development exercise for the teaching team. Also it should be noted that the team dynamically changed the lecture and tutorial work to reflect the needs of students as the subject evolved. Students self-select their subjects. After the first three weeks of the subject, there were a number of drop-outs who felt that the subject did not suit them. This might have contributed to the higher pass rate.

CONCLUSION

This paper emphasises that in order to enable students to conceptualise a framework for designing for emerging interface technology like ubiquitous computing, it is not enough to teach design techniques. Designing and understanding are iterative and interrelated activities. To design for any work practice, it is important to acquire a good knowledge of the work practice as well as analyse the context and location of activities from multiple perspectives using multiple, appropriate representations.

In this subject, students immersed themselves in an ethnographic investigation of their own work practices as participant-designers. They were encouraged to conceptualise key activities from multiple perspectives. The Locales Framework, work practice categorization and rich pictures all gave them multiple views of the same ethnographic data. They used technology probes to consider some ways of enhancing their work practices. The focus of the design work was to draw on the interactions within a group of collaborating people to create deeper understanding of their work practices that led to a set of requirements for ubiquitous support for student group work. They designed support artefacts for student group work using both deductive and creative processes. Use of technology probes and physical model building gave them concrete representations of the designed artefacts. Different ways of testing out mockups using contextual scenarios and role-play added richness to their design.

The evaluations show that students valued the range of techniques they learned; our evaluation was that the design process was successful. However it is to be noted that success of this kind of subjects requires substantial support and resources from the teaching staff and the participating students.

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