Smartening up the Student Learning Experience with Ubiquitous Media

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This paper describes how an experimental platform for social, mobile and ubiquitous computing has been used in a wide-ranging longitudinal "in the wild" case study of the platform with a set of third-party services. The paper outlines some of the relevant aspects of the platform, including built-in support for community formation, for context sensitivity, automated learning and adaptation to the user, and for management of privacy and trust relationships. The platform architecture is based on the notion of Co-operating Smart Spaces (CSSs), where a CSS is a partition of the platform corresponding to a single user and distributed over the devices belonging to that user. Three of the case study services were intended for use in a physical environment specifically created to support ubiquitous intelligence; they were highly interactive and used shared screens, voice input and gestural interaction. Another three ubiquitous services were available throughout the university environment as mobile and desktop services. The case study exploited this architecture's ability to integrate multiple novel applications and interface devices and to deliver them flexibly in these different environments. The platform proved to be stable and reliable and the study shows that treating a provider of services and resources (the University) as a CSS is instrumental in enabling the platform to provide this range of services across differing environments.

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1. INTRODUCTION

Ubiquitous computing and social networking are two important paradigms in computing today. Ubiquitous computing arises from the need to deal with increasingly complex environments surrounding the user, as the numbers of intelligent sensors, devices and services continue to grow at an ever more rapid pace. Its goal is to create an intelligent environment which will support the user in managing and interacting with these devices and services unobtrusively. On the other hand social networking is concerned with communication and interactions between people. In recent years, online social networking has significantly improved social connectivity between users and has opened up a range of new opportunities for exploiting the Internet.

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However, these two paradigms are complementary in many respects: ubiquitous computing is concerned with the user's interactions with devices and services, social networking with his/her communication and interactions with other people. Thus, if one can combine the two in an integrated and seamless fashion, one could create a powerful system with the properties of each together with additional advantages gained from combining them together.

This was the goal of the SOCIETIES project, which has investigated how these two paradigms can be seamlessly integrated into a single system [Gallacher et al. 2013], and has designed an open, scalable architecture to achieve this. This architecture delivers mobile and ubiquitous services to users and enables users to share services with one another. Based on this a platform was implemented which supports context-awareness, personalization, machine learning, and mechanisms by which users can manage their privacy, trust and individual preferences when they interact with the services. Services are provided with social context that applies not just to individual users but also to groups and communities of users.

In order to test these ideas and evaluate its usefulness, three separate user groups were selected. These were:

(1) Disaster Management. The potential for a system that combines ubiquitous computing and social networking functionalities in a disaster scenario could be significant and a group of disaster management experts were identified to evaluate the platform in this context. Initial reports on this are given in [Dingqi et al. 2014] and [Floch et al. 2012].
(2) Business Enterprise. A set of workers from industry was selected to evaluate the platform in the context of providing support for delegates at a conference (or other business meetings).
(3) Students. A group of university students at Heriot-Watt Universitywas chosen to evaluate the platform in a university setting. The advantages of this group are that they are highly adaptive and readily adopt new technology.

The platform has been evaluated over the course of its development through case studies involving each of the three user groups. Whereas most of these were very short, this paper describes a larger "in the wild" case study of the platform together with a collection of services, which was carried out in a university environment. In this case study a set of student volunteers were allowed to make free use of the platform and a set of services over a continuous six-week period in the last quarter of 2013. The services combined aspects of social, mobile and ubiquitous computing and the case study as a whole included: social computing; mobile devices; location tracking via RFID and GPS; gestural input via Kinect; adaptability to social and individual context; mechanisms for automated learning of individual and group preferences; explicit negotiations with users over privacy terms and conditions using privacy preferences; and interaction with an immersive intelligent environment.

The different services supported by the platform during the case study varied widely in their purposes and in their models of the user interface, social interaction, personalisation and learning. The platform and some of its services were available throughout the university and outside, using technology available on smartphones and desktop computers. The university also hosted a communal area known as the Learning Zone, which offered a wide range of devices for location, interaction and display and enabled an immersive experience for case study participants. Some services offered by the platform were designed to take advantage of these facilities.

The next section gives a brief overview of some relevant aspects of the platform while section 3 provides some background to related work. Section 4 describes the Heriot-Watt University Learning Zone, the ubiquitous space within the university. Section 5 provides some detail on the case study services and section 6 describes the case study itself. Section 7 gives an outline of the data analysis while section 8 presents some results and section 9 concludes with a discussion of the case study outcomes.

2. THE SOCIETIES PLATFORM

The SOCIETIES platform is based on the notion of the Co-operating Smart Space (CSS). Individual users and representatives of a single organization each interact with the platform via their own partition, or Co-operating Smart Space (CSS). The CSS manages ubiquitous resources belonging to the user or organisation, together with their individual context and preferences. A CSS may also share resources or services with other CSSs.

Another important concept is that of a community, which consists of a collection of CSSs. An individual CSS can set up a community which one or more other users or organizations, who share some common context, may join. Each individual user may belong to any number of communities.

One important role of the community is to enable the sharing of services and resources between all CSSs which are members of that community. To obtain full value from this functionality, the idea of dynamic communities is introduced through the discovery, connection and organization of relevant people, resources and things. This crosses the boundary between the physical and virtual world [Anagnostou et al. 2012]. Applications and services interact with communities and CSSs, thereby providing a modular and scalable way to develop ubiquitous social software.

The SOCIETIES platform provides a range of facilities to support social and ubiquitous computing [Roussaki et al. 2014]. The platform supports services which adapt to the user's context and preferences and which learn from the user's behaviour and interactions with the system. It supports users in maintaining privacy and different levels of trust in services and in other users or organisations. It provides an interface through which users can communicate with other users and explicitly inspect their own settings and the system's inferences about them. It provides functionality to support third-party services such as those described in Section 5. Users can interact with the platform itself via a web browser and (with more limited facilities) on the smartphone. Users can create and join communities; watch the activity feeds for communities and for other users; install, share and run services; maintain their user profile; and manage their preferences, privacy settings and trust settings. The remainder of this section describes the mechanisms for context, user preferences and privacy in more detail.

2.1 Context

Adaptation to the user's context is key to offering users a seamless experience of ubiquitous media [Gallacher et al. 2013]. The platform enabled services to be context aware and to adapt their behaviour according to the users' context. The platform's context mechanisms operate at both individual and community levels. The platform maintained a relational database of information about the context for each CSS and community. Context data updates could be triggered by sensors, user actions, changes in social media data, community activity, community membership changes, etc.

During the case study, the key elements of the users' context to which the case study services adapted were the users' location and the time of day. In the case of location three different sources of location data were used within the system, although for the student case study only two of these (RFID and GPS) were used. Context was handled at multiple levels of abstraction. Location was tracked both by physical co-ordinates and by symbolic locations. Time was recorded through the system clock, and then abstracted into larger distinct time periods – morning, afternoon and night. These abstractions were used by the system and third party services. A context refinement process is also incorporated into the platform. Its main function is to improve the quality of the context data. For example, where different sources of the same data are available, it uses inference rules to deduce the best value for the data. This is particularly useful in the case of location data where different mechanisms are used to infer the exact location of the user.

2.2 Personalisation

We use the term "personalisation" to refer to the set of techniques used to adapt the behaviour of the system to meet the needs and preferences of an individual user. In this case the system may take different actions depending on the current conditions (context) and the particular user. For example, this may affect the selection or initiation of a third party service, the parameters that are passed to a service, the response to a request for personal information on the user, etc.

In the SOCIETIES platform different approaches are used to determine when to take action and what action to take. Four mechanisms were particularly relevant to this case study, viz:

(1) User preferences. A user preference outlines what an individual user prefers in some contextual situation [Gallacher et al. 2013]. It can be regarded as a rule of the form

IF context X arises **THEN** do action Y

although in practice the process is more complicated.

(2) User intent [Gallacher et al. 2011]. This assumes that certain actions naturally follow others, and the system, maintains sequences of actions and their associated contexts for a particular user. If the system recognizes that the user is part way through a known action sequence, it can determine what future action should be performed if a matching context is detected. Two different approaches were used based on user intent, namely:
  (a) Context Aware User Intent (CAUI). CAUI builds a task graph based on the user's past sequence of actions/choices that represents the likelihood of their next action/choice taking into account their context.
  (b) Conditional Random fields Intent System (CRIST). CRIST builds sequences of actions/choices also taking context into account but based on conditional random fields [Doolin et al. 2014].

(3) Neural net. A neural net approach has a major advantage in that it operates incrementally, and uses every relevant event to predict actions. Thus it can adapt more quickly to change than the preceding two approaches.

These four mechanisms operate in parallel, and whenever an appropriate event occurs, may predict an action to be performed. Since they do not always agree, these predictions are passed to a conflict resolution process which uses additional information, including the Confidence Level and date of last update of each preference rule, to arrive at a final decision. Whatever the final decision, unless otherwise specified, the system will notify the user (via the mobile device or web interface) and give the user the opportunity to intervene and halt the action if it is not what he/she wants. If the user does not halt the action, he/she could also choose to accept the prediction for future use without further notifications.

2.3 Machine Learning

It is generally accepted that any system based on using user preferences needs to make use of some form of machine learning to acquire and maintain these preferences. As the set of devices and services grows and the contexts in which they are accessed increases so too does the need for suitable machine learning support. Consequently the platform provides the necessary support to automatically learn preference rules from the users' earlier actions in context.

The challenges facing the machine learning mechanisms include the following: they must be able to extract accurate preferences from the monitored contexts and behaviours in a constantly changing environment; they must be able to keep the preference set up to date by responding rapidly to changes in users' behaviour while at the same time remaining less sensitive to noise from small deviations in their behaviour; and it must also be possible to present the user's entire set of preferences in a way that is understandable and that allows the user to change their own preference set explicitly.

For the preference rules the learning mechanism used was based on Quinlan's C45 mechanism. For the user intent a purpose-built algorithm was used to identify recurring sequences of actions. In the case of the neural net, learning is dealt with automatically.

2.4 Privacy and Trust

Privacy protection is integrated into the platform and supports the users in managing their personal data [Doolin et al. 2014].

The SOCIETIES mechanism provides negotiation functionality between CSSs when one CSS installs a service shared by another CSS or between a CSS and the administrator of a community when that CSS requests to join that community. When users subscribe to a service or join a community they are notified about the personal data that may be shared with the service or the community, and can configure the terms and conditions for disclosing this data. They may also change permissions subsequently. Personalisation and learning are also applied to privacy negotiations so that the platform can learn users' privacy preferences and (with the users' agreement) apply them automatically.

The platform also provides mechanisms for users to manage trust in services, individuals and communities [Roussaki et al. 2012]. Users can find the trust levels given by other individuals and communities, and can connect to other individuals, services and communities based on trust levels. Novel mechanisms combine and distinguish between direct trust, which is based on the user's own interaction history, and indirect trust, which is based on the trust behaviour of other members of the user's community.

3. RELATED WORK

The study described here is novel because it evaluates a mobile social and ubiquitous system by allowing participants free use of the system over an extended time period. Few case studies of ubiquitous computing have extended over such a long period. Longer-term studies in social computing usually focus on existing software while studies of novel ubiquitous computing are usually shorter. The extended time period was essential due to the social nature of the platform and to enable automated learning and adaptation. The case study combined a number of different services in different environments, with some usage in the highly immersive Learning Zone and other usage distributed throughout the university and off campus. Students could choose to use whichever services, platform features and environments they preferred. This unconstrained use of the system explored how they would build up communities, how they would integrate the services into their social and working lives, and whether they would find novel and creative uses of the platform and its services.

Various strategies have been recommended for evaluating ubiquitous and mobile computing. Laboratory studies offer a controlled environment where use of a mobile system can be closely monitored [Kjeldskov et al. 2004]. Field studies complement laboratory studies by gathering information about how novel technologies are used in realistic settings [Robinson et al. 2012] and they are especially important in ubiquitous computing because it is closely involved in users' everyday lives [Brown et al. 2011]. Field studies provide different and valuable insights into how people perceive new technologies and how they appropriate them into their existing practices [Rogers et al. 2007].
Some studies assign tasks to users which exercise particular features of the technologies which are to be studied (e.g. [Robinson et al. 2012]). Our study allows users to integrate ubiquitous technologies into their own practices as they choose, and to develop novel and creative uses for them [Rogers et al. 2007].
However, difficulties remain in conducting in-the-wild case studies for ubiquitous technologies. Although technological improvements have made such case studies more feasible [Brown et al. 2011] they are still difficult and time consuming. Studies have explored the role of mobile smartphones in ubiquitous computing because they accompany people everywhere and their use is so deeply embedded in everyday life [Barkhuus and Polichar 2011] but evaluating novel software on mobile smartphones is difficult due to the range of different devices in everyday use [Guo et al. 2012; Kjeldskov et al. 2004]. In the SOCIETIES case study it would not have been feasible to implement services and interfaces to the platform on the many different mobile phones that students might own and so one mobile device was selected and distributed to participants.

One of the first user studies of a large group of people using a social and ubiquitous system in situ for a continuous period of time was Miluzzo et al's study of CenceMe [Miluzzo et al. 2008]. CenceMe used the sensors in an off-the-shelf mobile smartphone to infer contextual information about the user's location, activity (such as sitting or walking) and social context (dancing with friends or in a restaurant), and shared this with the user's social network. The study lasted three weeks with 22 participants who used it throughout a university town. CenceMe performed a single function (inferring contextual information) and shared it within existing social media services such as Facebook. The SOCIETIES case study was of a comparable size and used a range of specially developed ubiquitous services in which the users' contextual information modified the behaviour of the services.

In situ studies over an extended period have been applied to assess and compare mobile interfaces for social media. McGookin [McGookin and Brewster 2012] describes a smaller field study of an auditory social display. This field study uses a single application to evaluate the implications and design issues for auditory display of social data, also giving a comparison of two types of auditory display for social data. The study lasted two weeks, one week for each display, and involved five users.

Studies which combine multiple social tools have generally involved existing tools with established networks of users (e.g. [Matthews et al. 2014; O'Hara et al. 2014]). Matthews performed interview analysis and linkage analysis to study how online communities within an organisation combine multiple social tools. The tools under analysis (wikis, blogs, forums, social file repositories, social bookmarks and task-oriented spaces) were social but not mobile or ubiquitous.

Software designers are increasingly taking advantage of the range of in-built sensors [Miluzzo et al. 2008] and non-visual feedback [McGookin and Brewster 2012] [Robinson et al. 2012] on mobile smartphones to provide a richer sensory experience that does not dominate users' attention by forcing them to type or to look at a screen frequently. Used in this way, mobile phones move towards offering the smooth, calm experience envisioned by early promoters of ubiquitous computing, a vision in which devices merge into the background of everyday life, invisibly noting the needs and wishes of users and responding to them equally seamlessly. More recently there has also been a recognition that there are limits to seamless invisibility and it is not always desirable [Bell and Dourish 2007] and the focus has shifted to ubiquitous computing that directly engages and even challenges the user, recognising that conscious engagement with the technology and even with gaps in the technology can add value to its use [Rogers 2006].

In our case study two separate mechanisms were explored. On the one hand mobile smartphones were used as the main peripheral devices in the case study. On the other hand we set up a communal ubiquitous environment called the Learning Zone where other devices were available. Here large shared screens offered an alternative display mechanism and Kinect devices were used for gestural and voice input. In addition RFID equipment was installed to track the locations of students within the Learning Zone, on the basis of RFID tags carried by them.

The greater level of instrumentation in the Learning Zone corresponds to a "living lab" [Abowd 1999; Rogers et al. 2007] in which environments such as the home or classroom are simulated or extended and instrumented to sense and measure human behaviour in that setting. Special events were held in the Learning Zone to showcase and demonstrate features of the system that could not be demonstrated elsewhere, in a setting that was generally used by the students for everyday social interactions. The Learning Zone and its ubiquitous facilities were freely available throughout the extended study, and results from system usage in the Learning Zone were combined with results from usage outside this specialist area.

4. THE LEARNING ZONE

The Learning Zone at Heriot-Watt University (Fig. 1) was created as a ubiquitous intelligent environment and set up as a fixed "smart space" [Papadopoulou et al. 2012]. Three large display screens, three Xbox Kinect devices with motion detection cameras and an active RFID reader system were installed in a communal student area to convert it into a ubiquitous and intelligent environment.

Within the Learning Zone several RFID Wakeup Units were installed dividing the environment into unique areas. Each user was given an RFID Tag, unique to them, to allow the SOCIETIES Platform to track their locations within the Learning Zone. A component within the University CSS, the Display Driver, would retrieve the mapping between RFID tags and user CSSs and update the corresponding CSS symbolic location to the location which is represented by the Wakeup Unit in the CSS's context database.

Each of the three display screens was associated with one of the symbolic locations provided by an RFID Wakeup Unit. A component within the University CSS, the Display Driver, would listen for symbolic location context change events. When the user entered the vicinity of the RFID Wakeup Unit associated with a screen, the Display Driver checked the availability of that screen. If the screen was available, the user was issued a

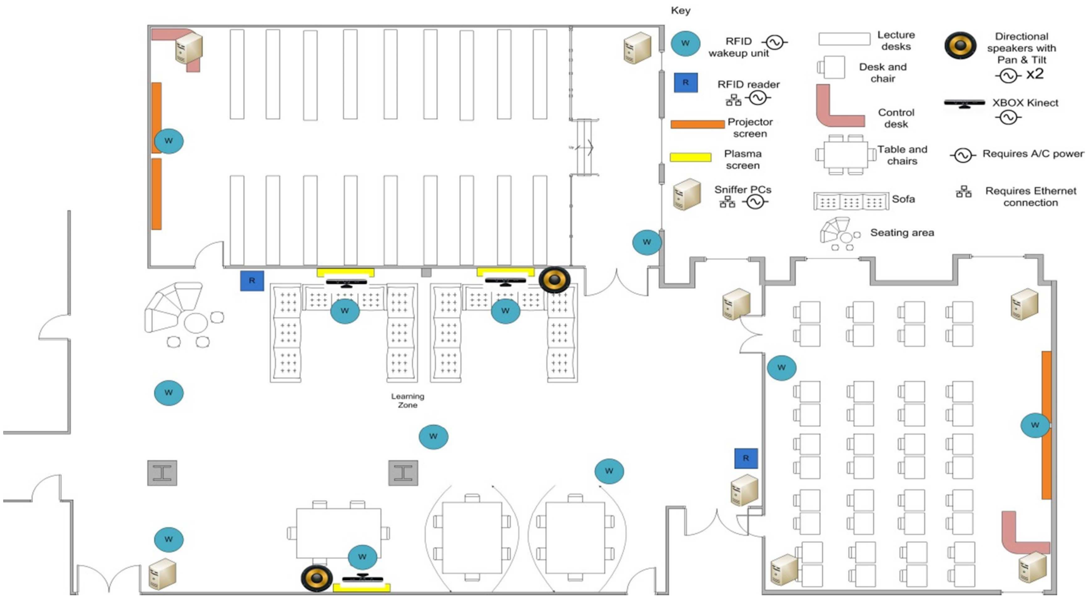

Fig. 1. Heriot-Watt University Learning Zone.

User Feedback notification asking whether they would like to start a session with the display screen. If the user responded positively, the screen loaded a user interface, called the Display Portal. The Display Portal presented the user with a list of available services.

Several issues can arise in a multi-user ubiquitous environment. Consider the following two scenarios:

- Several users walk to a screen simultaneously.
- A user does not respond to a notification.

The Display Manager used a 'first-come, first-served' basis when allowing users to start a screen session. When a user's symbolic location changed to a location which had a display screen, the Display Manager checked if the screen was already in use and if not a User Feedback notification was issued. When a user responded to the User Feedback notification, if the user remained in that location and no-one else had accepted a notification to use the screen, the screen would then become unavailable to others and the user could connect to the screen and select a service.

A pilot version of the configuration tested prior to running the case study connected the user to the screen immediately when their RFID device was detected near a free screen. This was problematic because being in the area did not necessarily mean a user wished to interact with the screens, and furthermore while one user was connected to a screen no other user could access it. Hence it was decided to notify the users and allow them to decide explicitly to connect.

Issues also arose from the "in-the-wild" setting. The Learning Zone was chosen because it was accessible to the students and widely used by them. It was a public seated area outside three lecture rooms and was a busy, often noisy location. It was used as a social space with seating and tables, and occasionally as a display space to host exhibitions of students' and visitors' work. It could become very crowded as students gathered there before lectures. The inclusion of interactive services in the Learning Zone led to some challenges. One challenge was that of detecting presence at one of the screens. A user's presence was initially detected at a screen via RFID, they interacted with the screen via the Kinect device and they could break the connection either by explicitly logging out or else by walking away from the RFID unit. Location information from the RFID was continuously updated but some areas were not picked up by any RFID device, and the coverage varied somewhat with the arrangement of metallic display boards. RFID locations around the screens did not correspond exactly to the users' sightline. This led to difficulty in how to interpret the "disappearance" of an RFID tag from a location. A user might still be using that screen via the Kinect or their mobile phone and so losing the RFID signal was not in itself interpreted as leaving the screen. Instead the RFID units that were placed near the entrances and exits of the Learning Zone were used to detect when users had left the screens. This solved the problem of disconnecting users from the screens unintentionally but led to a converse problem: if the exit RFID units failed to pick up a user who had left a screen without logging out then the system did not detect their absence and would leave them in control of the screen.

Other difficulties were caused by the busyness of the Learning Zone. The Kinect voice recognition interface was affected by background noise and detected fewer instructions when many people were in the room. It would also incorrectly accept input from other people speaking nearby. If a group of people were gathered round the screens then the Kinect's gestural sensors could become confused and pass control to another user in the group although still logged in as the original student.

5. SYSTEM STRUCTURE AND SERVICES

The case study was structured with one CSS for each student participant and one CSS to represent the University. The University CSS held the resources and services to be shared with the student participants. The University CSS mediated the resources in the Learning Zone. The services held by the University CSS were shared with the students via a community created for the case study, called the University community. The University CSS owned this community and at the beginning of the case study each student participant CSS was enrolled as a member of this community. As services were unrolled during the case study they were distributed via the University community (Fig. 2).

[Taylor 2008] proposed a flexible and adaptable Personal Smart Space (PSS) and [Papadopoulou et al. 2012] describe an extension in which communities can be created and resources shared between peers as the occasion demands. The case study architecture combines the flexibility and adaptability of the peer-based PSS with the benefits of a client-server architecture in which a CSS that represents the university shares the resources in the Learning Zone and distributes services to student users.

For some services, the University CSS hosted a server version of each service and distributed a client version as shown in Fig. 3. For example the server version of the Collaborative Quiz held the quiz questions and answers. Other services were provided and hosted outside the university by other project partners. Access to all services was distributed by the case study managers via the University community.

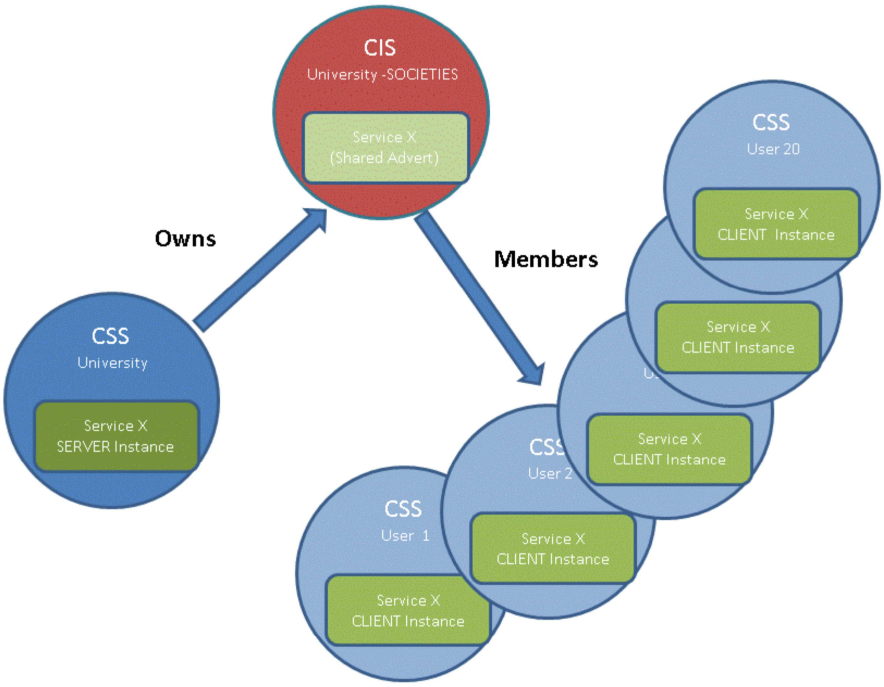

Fig. 2. Service Sharing via the University community.

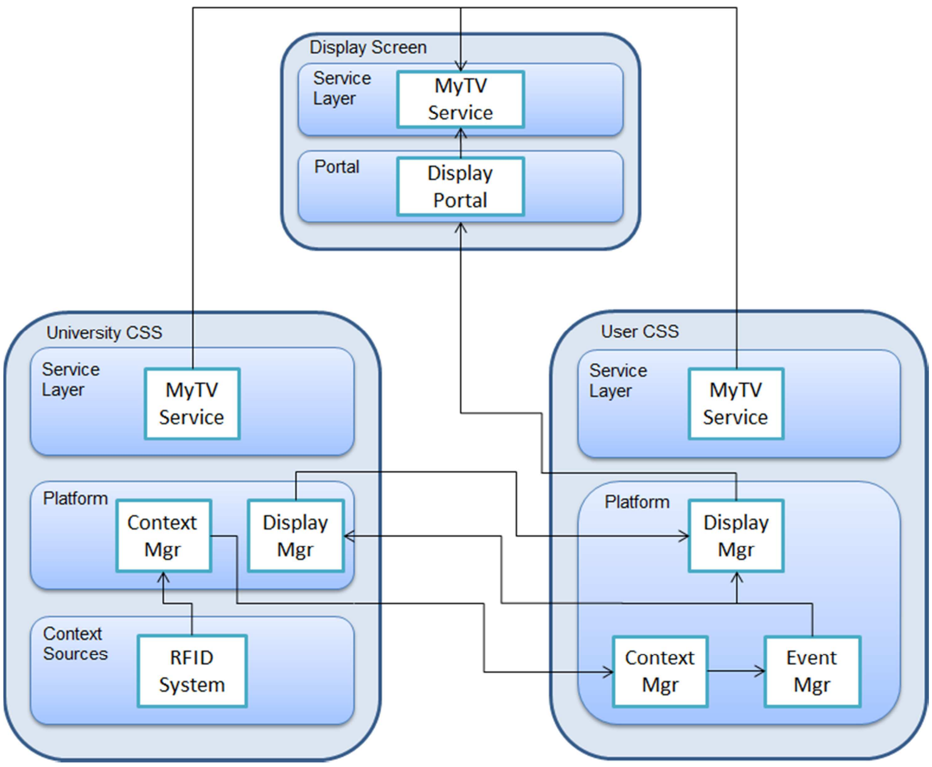

Fig. 3. System Architecture for the Learning Zone (MyTV Example Service).

The platform supported six services which the students could call up for both educational and recreational purposes. The six services offered different aspects of ubiquitous computing and the platform in various combinations (Table I). AskFree, MyTV and the Collaborative Quiz demanded a high level of interaction from the users, making use of the large shared screens for display and the Kinect for gesture-based interaction and voice input. CoBrowsing, MyTV and the Calendar used automated learning of users' actions and preferences. AskFree, GeoFencing, Collaborative Quiz and MyTV were responsive to the users' location context, GeoFencing used GPS to locate the user while the others used RFID tags. CoBrowsing and the Calendar were web-based applications.

Table I. User Interface and Platform Features used by Case study Services

	User interface devices						Platform features		
	Mobile Device	Web	Shared Screens	RFID	Gesture	Voice	Social	Learning	Contextual Adaptation
AskFree	✓		✓	✓			✓		✓ Location
MyTV			✓	✓	✓			✓ Channel	✓ Location, time
Collaborative Quiz			✓	✓	✓	✓	✓		✓ User interests
CoBrowsing		✓					✓	✓ Web site	✓ User interests
GeoFencing	✓						✓		✓ Location
Shared Calendar	✓	✓					✓	✓ Events	✓ Location, profile, time

5.1 AskFree

AskFree was intended to enable students to ask questions on their smartphones during a lecture without interrupting the lecture. The typed questions appear on a screen and are visible to the lecturer. Similar questions with different wordings were recognized using natural language processing techniques and merged. During the case study this service was available on the shared screens in the Learning Zone and interaction was via the students' mobile smartphones.

5.2 MyTV

MyTV allowed students to select TV content on the nearest ubiquitous screens in the Learning Zone. The service provided four different channels each with a different topic: news, sports, music and cartoons. MyTV used RFID location to connect to the nearest screen. It used context learning to select channels automatically according to the user's previous selections at different times of day and on different screens.

5.3 Collaborative Quiz

The Collaborative Quiz was intended to allow students to extend their learning by offering quizzes related to their recent lectures. During the case study the Quiz was available with general knowledge questions on the screens in the Learning Zone. Students could answer individually or form teams via a community to answer collaboratively. When the Quiz was used individually it could offer categories of questions related to the interests expressed in the user's profile. The Collaborative Quiz was integrated with the Microsoft Kinect device to allow gestural input. Multiple choice answers were presented on the screen and the system offered one of three input methods for the user's response, selected at random by the system. The three input methods were: a combination of striking a specific pose and a voice command; or a voice command alone; or a hand gesture to select a button on the screen.

5.4 CoBrowsing

CoBrowsing allowed students in different locations to browse the web collaboratively for information related to their subjects. Users could synchronize the web pages they were viewing, fill in form data together or ask questions in a chat about the currently viewed content. Each participant could see the others' mouse pointer on the shared page. A student could select (or create) a community and invite other students to join the session via the community, with invitations sent to its members and displayed in its activity feed. Remote co-browsing was supported by a voice/video chat facility on Google Chrome, Firefox and WebRTC. This service used the platform's learning mechanisms to recall the web sites accessed by co-browsing users.

5.5 GeoFencing

A geofence is a virtual perimeter for a real-world geographic area. The GeoFencing service allowed users to create their own geofences using the GPS on their smartphones. They could specify the location and radius of the geofence area. The GeoFencing service also tracked events associated with other registered users crossing the perimeter. When a GeoFence was created a corresponding community was created for it. Other users who crossed into the area were notified via their smartphones and offered membership of the community with a privacy negotation, and on leaving the area they automatically left the community. Users could discover the presence of other users inside the perimeter if they were also members of the same community. Communication and information sharing among the users was made possible by the activity feed of the community.

5.6 Shared Calendar

The Calendar service supported the traditional operations of smartphone calendar applications, allowing individual users to create events and define their personal schedule. Calendars may also be created and shared within communities. The calendar has the ability to recommend nearby events that are relevant to the user or community's interests.

6. CASE STUDY DESCRIPTION

The aim of the case study was to monitor usage of ubiquitous media and services over a six week period of continuous use. Such longitudinal studies are rare but very important for two main reasons. Firstly they enable changes in the usage and attitudes of participants to be monitored over time. Secondly, they permit sufficient information to be gathered for meaningful learning and pro-active behaviours to be personalised on an individual basis.

6.1 Case study Participants and Equipment

The participants in this case study were computer science students who were mainly avid users of social media and were comfortable with digital devices. Students had collaborated with developers in earlier stages of the project through participatory workshops and wizard-of-Oz experiments. These earlier experiments showed that students saw value in joining ubiquitous communities. This student population saw their use of ubiquitous systems as conditional on their having control over privacy and the automation of services [Doolin et al. 2014].

The twenty participants consisted of seventeen undergraduate and three postgraduate students from the School of Mathematical and Computer Sciences at Heriot-Watt

University. Seventeen students completed the case study and took part in the final interviews. Three students formally dropped out before the end of the case study.

Each participant was issued a Samsung Galaxy S3 smartphone with pre-installed software, and an RFID tag. Students were introduced to the basics of interacting with the platform and managing their privacy settings and preferences at the start of the study. To make it easier for participants to become familiar with the range of services, the six services were introduced at intervals during the study. MyTV and the Collaborative Quiz were the first services introduced at the beginning of the case study; CoBrowsing and GeoFencing followed in week 2, and the Calendar and AskFree in week 4.

6.2 Support for participants

Participants were issued with user guides to the SOCIETIES platform and services. They were invited to induction sessions at the beginning of the case study and at intervals when new services were introduced. Support links were set up to enable students to communicate directly with the case study managers. The case study managers adopted a work shift pattern to ensure support was available between 08:00 and 18:00 on weekdays during the case study. A Facebook group was used to broadcast important messages, such as system downtime and updated features. Email lists were created to broadcast announcements. Email was also used for one-to-one communication between participants and case study managers.

6.3 Participatory events

Participatory events were hosted to showcase different services and encourage students to make use of them. The first event consisted of a quiz session making use of the Collaborative Quiz. A second event, “Fun Afternoon”, involved a racing game using the CoBrowsing Service, an anagram competition making use of the AskFree service, and a competition using MyTV. The quiz event and fun afternoon were scheduled and held in the Learning Zone. The third event was a treasure hunt using the GeoFencing service at different locations across the university campus, which the students could undertake in their own time over several days.

6.4 Motivating and monitoring engagement

Various strategies were implemented to encourage use of the platform and services in ways that facilitate the evaluation. These strategies also enabled the trial managers to monitor the students' engagement with the trial and with the SOCIETIES platform and services. Participatory events were arranged to showcase the different services. Feedback was gathered via questionnaires at different stages during the trial. Rewards were offered for frequent and in-depth use of the SOCIETIES software and for completing feedback questionnaires. The students' use of the system and the different services were logged. The log data enabled the trial managers to identify creative and unexpected uses of the platform and services, and to make comparisons between the participants' activities as reported in final interviews and in the questionnaires and their actual use of the social and pervasive platform and services.

7. DATA ANALYSIS

Data about the participants’ use of services and the platform was gathered throughout the case study via log files and through the platform databases. The log files contained a date-stamped history of user and system activity. Snapshots of the platform databases were also taken regularly, allowing the state of the system to be recorded linearly whilst minimizing the impact on participants.

In order to track changes in participants' perceptions during the case study, four electronic questionnaires were posed at approximately weekly intervals during the case study. Individual semi-structured closing interviews were held with all participants who completed the case study. Each interview lasted approximately 45 minutes and was recorded by video.

7.1 Recording User Activity

Logs of student and system activity as well as the relational database used by the platform were recorded throughout the case study. The log files produced by the platform were automatically backed up daily, while the database was backed up each time the platform was taken offline. The platform log files were created using the Apache log4j API. In addition some third-party services created their own local log files. Consequently, a rich and complex set of user and system data was accrued for analysis.

The relational database recorded the context-sensitive, adaptive and personalised features of the platform and its services. It stored each user's context history together with their trust relationships and privacy settings related to other users, communities and services and their interactions with communities. It recorded the evolving learning structures (such as neural networks and preference rule sets) for each user. Data from the activity feed from each community, recording user interactions, was stored in the database. The platform database also provided detailed information about user interactions with those services which engaged context, i.e. the CoBrowsing, Calendar and MyTV services. The database recorded user interactions with communities and each GeoFence was represented as a community so the platform recorded when a user created a GeoFence or entered and left GeoFence areas.

7.2 Questionnaires

Four questionnaires were distributed via SurveyMonkey during weeks 2, 3, 4 and 5 of the case study. Completion was voluntary and students completed different numbers of questionnaires. The questionnaires captured usability issues and feedback comments during the case study. From these questionnaires, we were able to chart changes in the students' perceptions of ease of use and the value of the services offered as they changed over time.

7.3 Interviews

A comprehensive list of 37 questions formed the basis for the semi-structured closing interviews. This included questions about: the conduct of the case study; the infrastructure; the services; the interfaces for managing community memberships and preferences; the behaviour of the system; features for privacy, personalization and data sharing; social networks; and context awareness. Participants were also invited at the end of the interviews to give any other feedback not covered by the questions. The interviews were videotaped and analysed by deductive qualitative analysis. The Elan video analysis tool [Sloetjes and Wittenburg 2008] was used to support segmentation, transcription and annotation. The subject of questions provided natural themes which formed the basis of tiers for cross analysis and discussion.

8. RESULTS

8.1 Use of the Platform and Communities

Students made varying use of the system and services during the case study. During the 39 days when the case study software was available, students used the system between 9 and 26 days. The activity feed size reflects the number of interactions each student had with the platform, communities and some of the services and while it is not a complete picture it indicates the variation in activity levels between different students. All students were enrolled in one community (the University community) at the start of the case study and were free to create and join others during the case study.

Table II shows the numbers of communities (including GeoFence communities) which students joined during the case study. Some communities were created by the case study managers during the evaluation, for example the Treasure Hunt GeoFences and Quiz communities. Ten students created communities themselves, creating up to six communities each, and sixteen students joined at least one student-created community. (The high SD in the table is due to most students choosing to create or join a small number of communities.) The largest community created by a student had nine members in addition to its creator. GeoFencing proved a popular way to create communities, with students creating a total of nine non-GeoFence communities and thirteen GeoFence communities.

Table II. Students' use of SOCIETIES and Communities

Usage per student:	Minimum	Maximum	Mean (SD)
Number of days used	9	26	16.20 (4.8)
Activity feed size	55	583	264.20 (135.5)
Number of services used	1	6	2.70 (1.5)
No. of communities per student:			
Created	0	6	1.24 (1.6)
Joined (all communities)	1	8	3.59 (1.8)
Joined (student-created)	0	4	1.70 (1.1)

Fig. 4 shows how the students' perception of the ease of use of the SOCIETIES web interface and its presentation of communities changed during the case study. This chart sums the responses to two questions across the last three questionnaires (the question was not asked on the first questionnaire).

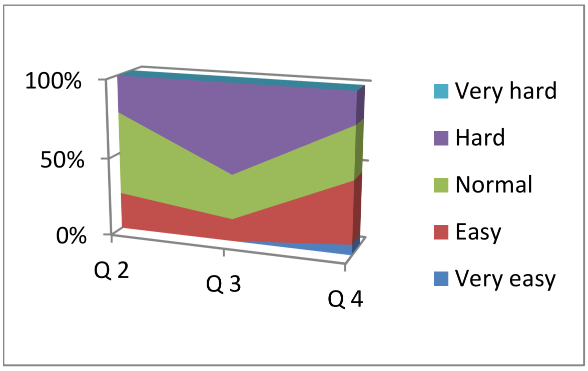

Fig. 4. Perceived Ease of Use: Change over time (Questionnaires).

No participant assessed the system as “very hard” to use at any time, but students experienced some operational difficulties with community creation and the overall response was that creating and manipulating communities was not easy although this did improve The chart also shows that their perception of ease of use first decreased as the students tried to make more serious use of the interface and communities, and then increased as they became more accustomed to them.

One difficulty in assessing communities was that the case study participants did not form natural social groups as they were studying different subjects, and timetabling and the pressure of other work made it difficult for case study participants to form groups informally. The participatory events were introduced to overcome this difficulty and provided a social structure in which students could explore the social aspects of the services. The benefits extended beyond the formal events. Gathering together in the Learning Zone for events encouraged the students to explore the system together informally and in ways that were creative and not mediated by the case study managers.

8.2 Use of Services

Comprehensive data about the students' interactions with the multiple services was analysed. The findings showed that students varied considerably in their use of the six services and combined their use in different patterns. We shall address each service in turn and follow this with some over-arching comments.

AskFree

The AskFree service was introduced to students during the third week of the trial. AskFree was used by eleven students on three different days, excluding the Social and Pervasive Afternoon participatory event but there was also some free use made of the service during that event. The setting was not one for which AskFree was originally intended (asking questions during a lecture), instead it was made available in the public Learning Zone. During most of the trial, questions from all locations in the Learning Zone (including locations away from the screens) were amalgamated into a single session and the combined results were displayed on all three screens.

Much of the students' use of AskFree during the trial was experimental and exploratory. One group of students all asked similar questions on different screens to see how they were combined into one question. One student moved between locations to see that the question still appeared without the need to log in again. Two students found they could use AskFree to communicate with each other via the different screens, and expressed surprise and satisfaction at this functionality. Students also experimented with using AskFree for discussion purposes. Students used AskFree to discuss the Shared Calendar service, to raise questions about AskFree itself, and even to demonstrate how it might be misused. Some of the communications were humorous and others expressed enthusiasm.

During the Social and Pervasive Afternoon participatory event, AskFree was set up slightly differently to support the competition. Two independent AskFree sessions were created, using one screen each, while the third screen was being used by the trial managers. During the competition students found the longest word they could from a given set of letters and supplied the word to AskFree. Before the competition started, students had explored AskFree independently and two students used the scrolling sequence of questions to create a collaborative interactive poem/story on one screen.

In general the AskFree service was very well received and it was the service used by the largest number of participants. Most found it easy to imagine how it might be used in their educational environment to support lectures and it was considered especially useful for shy people who might otherwise feel too self-conscious to ask questions in a large class. The simplicity of the application appealed to some who didn't advise altering it at all, while others suggested extensions along the lines of the popular StackOverflow online application, for example to vote answers up or down or to provide a web service that could be used outside the immediate lecture situation so that questions and answers could continue to be browsed and answered after a lecture, operating like a shared memory resource for a class.

MyTV

MyTV was introduced at the beginning of the trial. It made use of the Kinect and screens in the public Learning Zone. MyTV was sensitive to the users' location through the RFID tags in the Learning Zone and it was integrated with the learning mechanisms for personalisation. A total of four students used it (apart from during the Social and Pervasive Afternoon participatory event). Use of MyTV was relatively low and so a competition using it was included in the Social and Pervasive Afternoon.

The response to MyTV was very divided. For the surprisingly large number of participants who did not watch TV usually in their everyday lives, MyTV did not seem to offer much value and they often professed a preference for using Internet services. However a small subgroup of participants in the trial reported that MyTV was the most impressive service. When asked if they would use MyTV outside the context of the trial, the need for social etiquette was raised. When considering whether MyTV could be used at home it was felt that it might be annoying if one person's preference over-ruled another's when they entered a room.

MyTV offered powerful mechanisms to learn their preferences for different channels on different screens and at different times of day. Not many students used MyTV often enough to see these capabilities in person and as a result participants did not always grasp the full power and capabilities of the system. One participant stated that they thought it was good that it learned your favourite channel but wasn't aware until interviewer explained that it could also learn to show different channels on different screens.

Collaborative Quiz

The Collaborative Quiz was introduced to students at the start of the trial. It was used by six students during the trial (apart from the Social and Pervasive Afternoon participatory event). Most quizzes were actually used individually. The Collaborative Quiz divided opinion. It was the preferred service of some who regarded it as "fun", "enjoyable" and "interesting", but was disliked by others.

This service was accessed from the screens in the public Learning Zone and required gestural use of the Kinect. A variety of input responses was required, ranging from asking participants to simulate button presses by controlling a virtual hand on the screen by moving their physical hand, striking particular poses to match that of an on-screen skeleton and using their voices for speech input. How students responded to the novelty of these motions and gesture interactions, and to the fact that this service was situated in a public space, were key factors in their views on the acceptability of the service. The increased challenge of gesture-based responses added to some participants' satisfaction in using it.

The potential for social use of this service, using it with friends, and the community aspect were also considered significant. Although we were unable to use the Collaborative Quiz for educational purposes during the trial, many participants identified potential benefits of using such a service in teaching scenarios. Its potential for use socially and competitively as a team was recognised by some as a possible additional educational benefit. The large public screens also facilitated vicarious learning as bystanders could learn by watching others taking the quiz. More than one participant considered that the Collaborative Quiz could be useful to reinforce individual learning, as a revision aid or a "checkpoint" to gauge personal progress.

CoBrowsing

CoBrowsing was introduced during the second week of the trial. CoBrowsing was used by a total of seven students, in addition to its use in the racing game during the Social and Pervasive Afternoon participatory event. Most of these sessions were experimental and the students tended to browse alone, rather than collaboratively, although two sessions were logged in which a pair of students did browse together.

CoBrowsing was assessed as being one of the less useful applications, with students commenting that they didn't see the need for it and that there were other, better, tools for collaborative work. However, when students compared it during the interviews to other collaborative tools such as Google Docs, its support for sharing between communities was seen as valuable. Two students commented that it could be useful for collaborative research for coursework, especially during group projects, and that with the addition of VOIP or text chat it would be able to support remote collaborations.

Interview responses suggested two reasons why Co-Browsing was not seen as useful during the trial. First, students lacked a social context in which to use it, as they were not currently working together on a joint project. Second, the students were not aware of the existence of a VOIP feature in the service, perhaps because it was not evident in the interface. When this feature was pointed out to them during the interview they agreed that this would make the service more useful. Several students also raised the need for an etiquette, or rules for use, for sharing control of the cursor.

Participants did not identify any novel uses for this service, seeing it as primarily for academic use. One student said he was unable to imagine scenarios when it would be useful to browse with someone else. However it is worth noting that the trial managers successfully applied the CoBrowsing service to a competitive visual game, perhaps suggesting that seeing the underlying technology more completely led to more flexible adaptation.

GeoFencing

The GeoFencing Service was introduced to the participants in the second week of the trial. Three GeoFences were created by the trial managers to demonstrate the use of the service should any participants come across them geographically. Shortly after its release, users started to report that occasionally they were experiencing minor issues with the service, in that the GeoFencing Android App would crash whilst users were interacting with it and no feedback was issued to the user when they believed they had entered a valid GeoFence. The developer was notified of these issues and a decision was made to allow the GeoFencing Service to remain available to the participants while improvements to the service were implemented. These enhancements were delivered in time to allow the GeoFencing service to be re-released in week 5 of the trial.

The GeoFencing service was mainly used during the Treasure Hunt event but several students also created their own GeoFences at other times. In total, 15 GeoFences were created by six trial participants. The interview responses suggest that students found it very interesting, especially using it in a context of creating their own communities to reference a geographical area. Eight students described it as one of the most useful or interesting services, making it the most highly rated service during the interviews.

Participants attempted to create GeoFences quite far afield, ranging from their own homes and gardens to as far away as a distant city. One participant went to a nearby city and set up several GeoFences in the hope that some other participants might find them but they didn't go to the same places. However he could confirm that they were there when he himself returned at a later stage. The student who travelled to a distant city also joined the nearby city Airport GeoFence.

Considering that the service was originally created for disaster situations, the students came up with many original ideas for using GeoFencing. Various social uses outside the trial were envisioned and one student described setting up a GeoFence in a fast-food restaurant to see how it could be used to support friends meeting, and was pleased to report that the experiment had worked. Some students suggested that it could be adapted to suit business needs. For example special offers could be offered to people as they entered a business surrounded by a GeoFence but they added that because the mobile device could only track location outdoors this limited the potential applications.

Shared Calendar

The Shared Calendar service was made available during the third week of the trial. Seven users made use of the service. The Shared Calendar was not frequently used, with most users only making use of it during a single day and logging only a single interaction, with a maximum of 7 interactions for one user. The Shared Calendar was seen as potentially useful, especially for sharing information between communities and social groups.

Most students did not discover its context sensitive features and the opportunities for personalised search and for automated personalisation and recommendations as they did not did not make enough use of the Shared Calendar to trigger the learning mechanisms. The main barriers to acceptability were seen to be the need to integrate with existing calendar programs, and the lack of an interface on the mobile device as this service was only provided via the Web App. The usefulness of the Shared Calendar service was seen to be dependent on the existence of like-minded communities using the social and pervasive system with a need to share information about events.

Some participants logged in once but didn't use it because none of their events were shared with the other participants and they had no reason to share them with any of the system communities. Another interviewee stated that s/he thought the service would be useful in a 'real world situation' for organising group events where group members could have their calendars updated with all the events and important dates pertaining to that group. Another participant suggested that community calendars which presented timetables and deadlines for a class would be useful in the university context. These interview responses indicate that although this service was not very popular or frequently used during the trial, it might have increased usefulness and desirability outside of the trial boundaries.

Summary

Table III summarises students' overall use and perceptions of the six services. It shows how many students used each service; which services they found most useful or interesting, as reported during the interviews; and how frequently they would wish to use each service as reported in the questionnaires (summarising all four questionnaires). AskFree was seen as a service that would be useful often. MyTV had the largest spread of responses, with the largest number of students saying they would use it daily but also the largest number saying they would not use it at all. Interview responses showed that this reflected participants' television-watching habits. For the Collaborative Quiz, the majority of the selections were for infrequent use. CoBrowsing responses were evenly distributed on the questionnaire, although feedback from the interviews was cautious. Two students said that it would be useful for coursework research and collaboration, particularly for

Table III. Usage and Perceived Value of Services

	No. of users	Rated most interesting/ useful (% from interview)	How often would you use this service in real life? (% from responses to all four questionnaires)					
			Never	<1 per month	>1 per month	Regularl y	Daily	Total
AskFree	10	36.5	0	22.6	32.3	34.5	9.7	99.1 %
MyTV	11	22.3	16.7	27.8	13.9	25.0	16.7	100.1 %
Collab.Quiz	9	4.5	0	58.3	19.4	16.7	5.5	99.9 %
CoBrowsing	6	13.6	18.2	40.9	27.3	13.6	0	100.0 %
GeoFencing	7	31.8	18.2	18.2	63.6	0	0	100.0 %
Shared Cal	4	18.1	16.7	50.0	16.7	0	16.6	100.0 %

group work where group members have to refer to a particular piece of code or other joint enterprise, and for remote collaboration. The number of students who said they would not use CoBrowsing at all decreased over the weeks.

GeoFencing was seen as the most interesting and potentially useful service in the interviews although students did not see it as something for frequent use. Participants attempted to create GeoFences far afield, ranging from their own homes to as far away as London (the case study being hosted in Edinburgh). Few students saw themselves using the Calendar frequently. Interviews revealed this was due to the need to integrate with calendar software that they were already using, and a lack of communities which required the sharing of events within the study group. It was, however, seen as potentially useful for communities and social groups.

Fig. 5 shows the change over time in the way students assessed how often they would use all the services. This chart sums the responses to six questions, one for each of the six services, for each of the four questionnaires, and is adjusted for the week when the students started using each service. There was an overall increase in the proportion of students who would use services daily or regularly, and a decrease in the proportion of those who would not use any service at all. As with ease of use (Fig. 4), the questionnaires show a “pinch point”, where students perceived less value at the third questionnaire (week 3) before an increase in value in week 4.

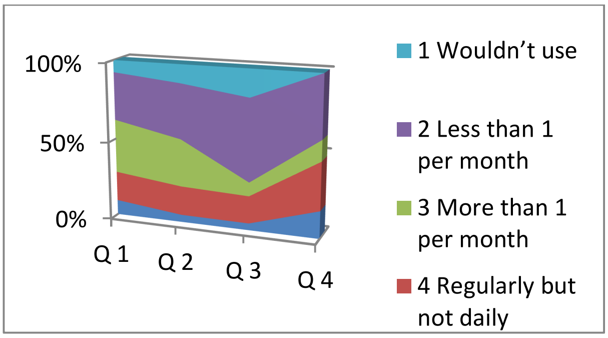

Fig. 5. Perceived Value of Services: Change over time (Questionnaires).

The architecture supported the creative use of its services by both case study participants and the case study managers creating uses for services that were different from those originally envisaged. For example, students used AskFree in a variety of creative ways. They used it to support discussion among themselves, humour and even poetry.

The GeoFencing service, originally intended to support rescue workers in a disaster management scenario, was applied to the Treasure Hunt; the AskFree service was used for the anagram game with single words as inputs rather than questions; and CoBrowsing allowed participants to race cars against each other graphically on a website. All these applications were successfully delivered without changes to the services' software.

8.3 Learning for personalisation

Table IV presents a brief summary of the results obtained from monitoring the four different mechanisms used for personalisation in the platform for a subset of six of the participants. These were chosen for their coverage of different third party services. Each firing represents a suggestion of a personalisation for an individual. When more than one mechanism makes a suggestion an executive system decides which suggestion to offer to the individual based on the degrees of confidence in the competing suggestions.

Table IV. Outcomes from Firings of Personalisation Mechanisms for Subset of Students

Firings per student:	Minimum	Maximum	Mean
Neural net	0	16	7
Preference rules	0	82	16
CAUI User Intent	0	274	113
CRIST User Intent	0	2	1

The Neural net uses a novel dynamic incremental associative approach which was developed especially for continuous use in the context-dependent personalisation domain, full details of which can be found in [Gallacher et al. 2013]. As described in section 2, the Preference rules approach uses an adaptation of Quinlan's C45 mechanism to learn decision rules and these are then applied when an appropriate context is recognised. The CAUI (Context Aware User Intent) and CRIST (Conditional Random fields Intent SysTem) are two different User Intent prediction mechanisms. As described in section 2.2, CAUI builds a task graph based on the user's past sequence of actions/choices that represents the likelihood of their next action/choice taking into account their context whereas CRIST builds sequences of actions/choices also taking context into account but based on conditional random fields [Doolin et al. 2014].

Not all of the personalisation mechanisms can be used for all the services and the mean values in the table reflect the fact that the CAUI user intent mechanism provided the greatest coverage in this respect. The CAUI mechanism generated more suggestions than expected and this was actually unhelpful at times. The maximum values indicate that all four mechanisms were active and made suggestions and the variations in this value are due to students using different services and on different numbers of occasions. The minimum values of 0 indicate that for each mechanism there was at least one student for whom it never provided a suggestion. This again reflects the varying usage of services made by the participants. Overall these results suggest that there is a place for learning both simple user actions/choices and sequences of such actions/choices in personalisation.

9. DISCUSSION

The architecture successfully supported a variety of environments and different social interactions within those environments. The Learning Zone with its immersive interfaces provided both technical and social benefits to the case study. By hosting the shared screens, Kinects and location sensing, the Learning Zone created a physical area where students could group together to engage with the system.

The Learning Zone highlighted social issues of using novel interactive services in a public space. Students reported that they had found the Quiz and its gestural interface highly engaging but also potentially embarrassing. Most students preferred to use it as part of a scheduled activity in the Learning Zone when they would be part of a physical group all engaged in the same activity and not as isolated individuals. In contrast, the GeoFencing service which used an unobtrusive and conventional mobile phone interface successfully supported a Treasure Hunt activity throughout the campus and students willingly set up their own GeoFencing areas in public spaces outside the university.

The case study platform proved to be robust in operating across different environments. It had been anticipated that the case study would start in a discrete operation mode in which the case study software and services were available for at least one scheduled day per week during the first weeks of the case study period, and more frequently when it became robust enough. In the event, continuous running of the platform was offered from the outset until the end of the case study, with only brief periods of downtime while problems were fixed and new features introduced. These periods were at night-time or during the very early morning when usage was low. Special activities were successfully hosted for extended periods of time.

Feedback from the users reflected this success. Most participants experienced some technical teething problems with the system but when system updates had been deployed, they recognised that the system had improved and was more stable and reliable.

Quantitative analysis of the use made of the various learning systems tested suggests that there is a place for learning both simple user actions/choices and compound sequences of such actions/choices in personalisation. The most appreciated elements of personalisation were those related to context awareness in response to location and time of day, which were exploited in the MyTV and GeoFencing services. Students who experienced the learning over time of personal preferences in MyTV expressed enthusiasm for it. Personalisation related to privacy preferences appeared to be less highly valued in that while some participants checked privacy settings initially, they did not change them or return to them. Interview data shows that this is because they felt that they were not sharing highly sensitive data and that they trusted the trial managers with their data, and that in a more demanding "real-world" setting they would also value privacy personalisation.

This study shows that a platform for social, mobile and ubiquitous and computing based on Co-operating Smart Spaces is effective in delivering novel social, mobile and ubiquitous services across different environments over an extended time period.

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