A generalised framework to support field and in-class collaborative learning

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Abstract: Mobile technologies have proven their value in field learning. Meanwhile, classroom technologies such as multi-touch interactive tables are gaining attention as well. With shareable interfaces and larger displays, multi-touch tables enable multiple students to interact and collaborate more flexibly. Thus, today's technology provides different means to facilitate learning both indoor and outdoor, in the form of specialised devices; yet an integrative view is missing in the literature so far. The goal of this paper is to propose a generic framework, capable of connecting different kinds of devices, such that the most suited device can be employed for each specific learning activity. Based on this framework, a pilot system has been developed that allows students to collect data through tablets on a field trip and share it with other peers via Bluetooth. Learners could also take part in a quiz, sent by the teacher to their mobile devices, and send their results back to the teacher through Bluetooth.

Keywords: mobile learning; CSCL; computer supported collaborative learning; field learning.

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1 Introduction

Research shows that a well-planned, effectively carried out and followed up field trip can play a vital role for improving learners' abilities to understand abstract concepts learned in the classroom by mapping them to real life (Farmer et al., 2007; Orion, 1993). Today's technology provides many means to facilitate learning on a field trip, particularly in the form of small mobile devices. Their mobility, small size, connectivity to the internet, user familiarity and ability to capture, present and transmit data in multiple forms make them natural choices for outdoor educational scenarios. In recent years, a lot of research has been conducted that illustrates the advantages of mobile devices for learning, especially for outdoor learning (Sharples et al., 2007; Rost and Holmquist, 2008; Alexander et al., 2010).

Another very important and established approach in education is collaborative learning, or more specifically in the context of computer technology, *Computer Supported Collaborative Learning* (CSCL). Collaborative learning is a process of shared construction of meaning through interaction and exchange of viewpoints; knowledge is built through the joint contributions of groups of learners rather than through individual effort only (Dillenbourg, 1999; Schneider et al., 2010). Research has shown that collaborative activities can produce far better results than individual efforts (Hockaday, 1984). Though small mobile devices are excellent for fieldwork, they may not always be the best choice for collaborative learning in classroom settings. Some kinds of collaborative activities have requirements such as larger displays which small mobile devices are unable to meet. Desktop and laptop machines have often been used for that purpose. Though they provide a larger display and better processing power as compared to mobile devices, they still have some limitations. For example, they cannot comfortably accommodate more than two or three members in a face-to-face discussion. Moreover, there would be only one active member who could perform some task on a device; the other members can only provide verbal input or feedback. Using a desktop/laptop with a multimedia projector could solve the view problem and more people could be involved in a discussion, but still only one member can be active. In addition, there are some further drawbacks with these settings. The members of such a discussion tend to focus on the projector or the desktop view instead of each other, which affects non-verbal communication like body language, gestures and expressions between the participants – which in turn is crucial for collaboration.

For face-to-face collaboration with activities such as brainstorming and discussion, the most effective way is sitting around a table. And, with all the facilities provided by technology for communication like video chat, voice chat, video conferencing (and no doubt these facilities work well when participants are not present in same room), the advantages of simply *sitting around a table* should not be ignored. When people are face-to-face, they do not communicate through words only. Non-verbal communication through body language plays an important role as well. Participants get a better understanding of other people's point of view by their gestures, expression and tone (Bollen et al., 2006).

Today, interactive multi-touch tables with shareable interfaces and large displays have become available. Multi-touch tables combine the benefits of sitting around a table and of computer-supported learning, and provide some extra features as well. The participants of a collaborative task are not just taking advantage of the face-to-fact setting and a shared view, but multiple participants can provide their input simultaneously or work on different (possibly related) tasks.

Now that technology provides sufficient means to augment both indoor and outdoor learning activities and communication infrastructure, we propose a general technology framework for learning that incorporates different kinds of devices (small mobile devices, multi-touch tables, standard desktops/laptops and interactive whiteboards) and combines their features to provide an integrated learning environment which is designed to support collaborative learning processes inside and outside of classrooms. To illustrate the idea of the framework, a pilot application that allows learners to collect various kinds of data on field trip and to share it with their peers via Bluetooth has been developed. The system also allows teachers to design multiple-choice questionnaires and to send them to learners through Bluetooth.

The rest of the paper is structured as follows. The next section provides a review of the relevant literature. Section 3 describes the motivation and main requirements for the framework. The structure and main components of the system are discussed in Section 4. Section 5 describes the pilot system and a learning scenario, illustrating how the system would serve learning support. A discussion and future work are presented in Section 6. Finally, some conclusions are presented in Section 7.

2 Literature review

In recent years, the focus of research on mobile learning has been of the 'field-trip' type. Those field trips could be a visit to a museum or zoo, or some outdoor task required in different subjects (i.e. ecology, ethnography, environmental study, and cultural and historical study) for primary, high school or university students. For example, MyArtSpace (Sharples et al., 2007; Vavoula et al., 2009) is a system involving high school students in a museum trip. MyArtSpace is a mobile phone- and web-based system which allows students to watch multimedia presentations of museum exhibits, take photos and text notes, and make voice recordings. After each action, the contents are automatically transmitted over a wireless connection and stored on a website. Later, in class, students can review their data, share it and make presentations. Another system developed to facilitate museum tours is MoMAt (Bitonto et al., 2010) that provides multimedia information about exhibits, based on cognitive styles of users. MoMAt is not specific for any particular age group or school grade. Wu et al. (2010) presented a system which helps elementary school students in learning historical and cultural contents. That system uses a mobile treasure hunting activity during a field trip. The mobile device helps students by presenting a treasure hunting map and clues; it uses a QR code to assess whether a student identified an object correctly or not Another application to support field trip activities is LEMONADE presented by Giemza et al. (2010) which helps students (and teachers) not only with data collection during a field trip but also for planning a trip (so-called pre-trip phase) and after the completion of a tour for evaluating the results (post-trip phase). Yin et al. (2013) presented a participatory simulation-based approach for mobile learning. The experimental results showed an increase in learners' motivation and significantly higher accuracy rates in performing more complicated sorting algorithm. A context-aware video-based prompt approach was proposed by Hung et al. (2014) to improve students' reflection levels. Here, the experimental results showed that learners' reflection levels were significantly improved and that positive attitudes towards the use of video-based prompts were observed.

An area that has been intensively investigated by researchers of mobile learning is language learning. Considerable work has been done in this particular field (e.g. Wong and Looi, 2010; Ogata et al., 2010; Yin et al., 2010; Li et al., 2010). Wong and Looi (2010) have presented a system called MALL that helps elementary school students in learning vocabulary and idioms from English and Chinese languages. MALL supports both indoor and outdoor activities. TANGO (Ogata et al., 2010) is an RFID- and mobile technology-based system used for vocabulary learning. Ogata et al. (2011) presented a Ubiquitous Learning Log (ULL) system called SCROLL that allows the learners to log their learning experiences with photos, audios, videos, location, QR-code, RFID tag and sensor data, and to share and to reuse the ULL with others. Their initial study showed the added value of the tool for learning English vocabulary. SONLUE (Yin et al., 2010) is a social networking-based system for mobile devices that helps learners find a native speaker to practice his/her second language. Li et al. (2010) describe an adaptive, mobile phone email-based system for vocabulary learning. This system sends tasks to a learner according to his/her interest and learning style and sets the difficulty level of a test according to learner proficiency level. SWML (Hsieh et al., 2010) is a system based on situated learning theory that helps elementary school students to improve their rhetoric abilities in Chinese. Lin et al. (2010) describe a sign language learning system on mobile devices with a 3D agent to facilitate communication with deaf and hearing-impaired people.

Some mobile learning applications focused on facilitating mathematics learning, including (Spikol and Eliasson, 2010) a system developed for elementary school students for learning geometry. The approach presented in this paper comprises both outdoor and indoor activities. Kalloo et al. (2010) have developed a game-based mobile application to help elementary school students learn mathematics. Go Math (Alexander et al., 2010) is another mobile application developed to help with mathematics in everyday life. Other applications designed to help students during fieldwork include (Rost and Holmquist, 2008) a system that helps university students of ethnography to collect data in the form of photos, audio, video and text notes during their fieldwork and automatically uploads their data to a website. That system also helps students to be aware of other students' activities. Another system that helps elementary school students in learning about butterflies is presented by Chen et al. (2004). That system allows students to take pictures of butterflies during an outdoor trip and lets them compare those pictures against a database. When the system hits a match, it provides information about that particular butterfly to the student. A similar application is presented by Chen et al. (2003) which featured bird-watching activities in an educational context (learning through scaffolding). Hsu et al. (2008) have used RFID technology to develop a system to help students identify plants in a schoolyard. Su et al. (2010) have presented an automatic scoring system for the evaluation of ecology observation worksheets.

The role of mobile devices for indoor collaborative learning has been widely investigated too. Examples include Mobile Notes (Bollen et al., 2006), which enables heterogeneous mobile input devices together with a collaborative modelling environment to be used in different discussion scenarios, e.g. classroom discussions, seminars or lectures. Qualitative analysis shows that certain activities are more suited to be enriched with mobile device input support than others (brainstorming and voting). Giemza et al. (2012) emphasised the need of integration for heterogeneous mobile devices into learning scenarios and propose the idea of applying different representations of the same content according to the capabilities of different devices. A pilot study indicated added value for learning. Collaborative note taking (Singh et al., 2004) enables students in a class to take notes on their PDAs and share them with their 'study group' in real time. The system has been evaluated in a graduate-level course and has proved to be a helpful utility. A constructivist-learning environment supported by handhelds is presented by Zurita and

Nussbaum (2004) for the teaching of reading for first graders. Study showed that children performing the activity supported with technology were observed to have significantly higher word construction test score than those performing the paper-based activity. Yang et al. (2013) discussed a concept map-oriented learning approach for supporting printed book reading through mobile devices with QR code. Their experimental results showed a significant increase in learning achievements as well as a high level of acceptance in terms of ease of use. Wu et al. (2013) presented a mind-map-based learning tool for supporting creative learning activities, and showed the effectiveness of their approach through a study conducted on a university management course. Hwang et al. (2011) proposed a concept map-oriented Mindtool for collaborative ubiquitous learning. Study results from a natural science course in an elementary school yielded that this approach not only enhanced learning motivation, but also improved the learning achievements of the students. Based on the results of a series of experiments, Hwang et al. (2014) showed that the students' learning performance as well as their in-field inquiry ability significantly improved, showing the effectiveness of the Mindtool-assisted ubiquitous learning approach.

Researchers also emphasised the need of proper learning strategies and well-designed helping materials in the context of mobile learning. Hung et al. (2013) showed that well-designed worksheets, instant feedback and supplementary materials provided through mobile devices can improve learners' field observation skills in an enquiry-based learning scenario. On the other hand, Chu (2014) conducted a study that showed that also within mobile learning scenarios, an improper learning design and heavy cognitive load can have a negative impact on learning gains. Hwang et al. (2013) aimed to investigate the effect of mobile learning models on students' cognitive load and learning achievements. Results showed that students who followed an enquiry-based mobile learning approach had a better learning achievement and less cognitive load than those who followed other models. While, in summary, we find a lot of research results focused on use of mobile devices for learning in the educational technology literature, there are relatively few examples that use multi-touch tables for education. This is not surprising as it is a (relatively) new technology. Examples include studies by Harris et al. (2009), Fleck et al. (2009), Hansen and Hourcade (2010), Olson et al. (2011), Schneider et al. (2010), Kaschny et al. (2010) and Morris et al. (2006). Harris et al. (2009) compared the effects of multi-touch vs. single-touch on interaction between young pupils while they are working on a collaborative task of seat planning. They report an enhanced collaboration when verbal and physical interactions between learners are taken into account (Fleck et al., 2009). Hansen and Hourcade (2010) present a comparison between multi-touch tables and multi-mouse set-ups and report users preferred to work on multi-touch tables. A case study of children's collaborative behaviour around a multi-touch tabletop interface that identified various collaborative behaviours is presented in Olson et al. (2011). They also noticed conflicts about interface elements, which were resolved by use of tangible wooden object. Piper and Hollan (2009) have compared the affordances of presenting educational material on a tabletop display with presenting the same material using traditional paper handouts. The study shows that students working on interactive table were able to perform better and solved problems on their own before resorting to answer keys. SimMed, presented by Kaschny et al. (2010), is an ongoing project for the use of interactive tables in medical education. Students in medicine are able to interact realistically with a virtual patient displayed on the interactive table. A system designed to facilitate foreign language education is presented by Morris et al. (2006). Evaluation shows that the table was an engaging platform for foreign-language education activities, promoting face-to-face discussion and providing students with feedback regarding their progress without necessitating the presence of an instructor. G-nome Surfer (Shaer et al., 2010; Shaer et al., 2011) is an application for enquiry-based learning of genomics using multi-touch table and indicate improved students' performance and reduced workload.

From the above literature review, it is clear that though excellent work has been done to facilitate outdoor learning activities, there are very few usage scenarios that integrate field activities with in-class activities. Wong and Looi (2011) also identified a research gap with respect to the four features of Mobile-Assisted Seamless Learning (MSL), i.e. multiple device types, multiple learning tasks, knowledge synthesis and multiple pedagogical models. Until now, the research on the use of mobile devices for outdoor learning activities and the use of multi-touch tables for indoor collaborative tasks have been progressing in parallel – an integrative view (which would certainly have benefits for learning sequences that involve indoor and outdoor activities) is missing in the literature so far. In this paper, we present such a generic framework, capable of connecting different kinds of devices (including tablet PCs, multi-touch interactive tables and electronic whiteboards) and the advantages that they offer. The framework provides a smooth communication between devices and facilitates both indoor collaborative learning and fieldwork.

3 Motivation and requirements

Some important learning concepts and requirements the framework needs to address are categorised in the form of requirements given below.

i *Ubiquitous access.* The first and foremost goal for the framework is to provide a truly ubiquitous environment for learning. Learners will be equipped with specialised devices for various tasks, whether it is a field trip or a classroom discussion, with the minimum effort required for the user to enable a communication between these different devices. This way, the main focus of the learners can be on the learning contents instead of thinking about how to switch from device to device and transfer data.

ii *Usefulness in multiple situations.* The key objective of the framework is an effective integration of the various learning scenarios and tasks. The framework should manage the sharing of learning recourses, enhance communication between learners, facilitate both co-operative and collaborative tasks, and provide assistance for learning *anywhere anytime*.

iii *Collaborative learning.* The framework should provide an environment for collaborative learning. Through the use of multi-touch tables, learners are not just sharing a common view and learning resources, but they have the extra advantage that the other devices like desktops, laptops and mobile devices lack: they can be face-to-face and communicate in a very natural way via non-verbal means like body language and gestures (Fleck et al., 2009). Moreover, the multi-touch interface can enable them to give input and perform actions simultaneously (Morris et al., 2006) which will make interaction more effective and as a result, create a more natural environment for a collaborative learning task.

iv *Interactivity.* A framework that combines the always-on-always-there feature of mobile devices with the shareable interfaces of large multi-touch tables would enhance the interactivity between learners, which is the key feature in collaborative learning. Such a framework has the potential to facilitate the sharing of ideas and information and making queries independently of whether students are in the same room or at some distant location.

v *Combination of the advantages of both 1:1 (one-to-one) and 1: m (one-to-many) devices to learner ratio.* Vavoula et al. (2009) have compared the advantages of a 1:1 vs. a 1: m device-to-learner ratio in typical learning situations. But in our view, this ratio can strongly depend on learning situations. For collaborative learning, a 1: m ratio could indeed be beneficial, while for individual learning, a 1:1 ratio may be a better choice. A general framework, which could incorporate multiple learning situations and select device-to-learner ratios accordingly, should combine the advantages of both ratios.

vi *Support for scaffolding.* Scaffolding is a learning mode in which an incremental support is provided to a learner by a more *knowledgeable instance*, which could be a teacher, a fellow learner or a machine. Moreover, as the learner's skills continue to develop, that assistance is withdrawn gradually until the learner is able to successfully complete some task without any help (Chen et al., 2003). Our proposed framework should have an embedded support for incorporating individual scaffolding and group scaffolding as well, where a teacher could provide assistance to a learner or group of learners by herself or other competent learners through appropriate devices.

vii *Domain independence.* One of the major goals for our framework is to build a domain-independent learning platform which should ideally be useful for all subjects in the school curriculum.

viii *Adaptation.* An important requirement is to offer enough flexibility to adapt available learning tools and material for new technologies like multi-touch tables.

ix *Support for everyone.* The framework should be useful for all the participants of a class, i.e. both students and teachers. It should, of course, be useful for students to fulfil their learning task. And, on top of that, it should provide assistance to teachers for designing exercises and learning activities for students and for assessing students' work.

x *Immediacy.* The framework would support simultaneous actions and the quick sharing of data, queries and ideas between learners, whether they are at distance observing something worth sharing with their fellows via mobile devices or whether they are working together around a multi-touch table and simultaneously performing some actions.

xi *Personalisation.* The framework would support both collaborative and individual learning, it would support different cognitive styles of users and it would allow learners to perform some personalisation, enabling them to create and manage their own learning resources and to create small learning networks.

xii *Seamless communication.* The idea of combining advantages offered by different types of devices in a general learning framework would be useless and rather cumbersome if a system based on this framework fails to provide a smooth and seamless communication model for all devices. So another major requirement would be to provide a smooth, fast and flawless data flow between devices.

xiii *Synchronisation.* An important requirement is that when multiple users are working on some collaborative task through multiple devices, a synchronisation of the resulting data across devices is performed.

4 System design

The proposed system has three essential elements: hardware, a communication infrastructure and software. We will discuss each of these in this section.

4.1 Hardware

To satisfy some of our primary requirements as mentioned earlier in Section 3 (Motivation and Requirements i, ii, iii, iv and v), the system would span on a range of hardware or devices which can be categorised into the following three classes:

- *Classroom technology*: it includes mainly the devices with large displays and support for group activities like interactive whiteboards and multi-touch interactive tables.
- *Field technology*: it consists of small devices like smart phones and tablet PCs, best for being used in outdoor activities like fieldwork and data collection.
- *Home technology*: it includes personal computers like desktops and laptops with their features of in-between classroom technology and field technology. For example, they offer support for multi-person usage and some mobility, but not as much as that offered by classroom technology and field technology, respectively. Nevertheless, their merits (processing power, memory and adequate view) and availability still make them essential to be considered within a generic framework.

4.2 Communication infrastructure

As stated in Section 3, a fundamental requirement for our proposed system is a smooth communication between different devices and between users of the system (mediated through devices). The system will provide a synchronisation mechanism that will manage the user resources across various devices and various user groups, i.e. personal data, public data (shared by the whole class), group data (shared by group members who are working on the same project) and teacher's data (teacher's resources).

To do this, the communication infrastructure will be designed as follows. First, it can be viewed on two levels:

a *Logical structure*. To meet the requirements of *support for everyone* and *personalisation* (Motivation and Requirements ix and xi), the system provides a separate space for each curriculum subject which is accessible to the participants of that particular subject (i.e. students and teachers). This logical space is further subdivided into the following:

- a public space,
- individual's spaces,
- group spaces.

The *public space* is accessible to all participants. The contents of this space can be copied to other spaces (individual's and group spaces), but the access rights for this space will be 'add and read only' for everyone except the creator of the content and the teacher, who could edit or delete content. Open messages, announcements, queries, timetables and teaching material will be provided in that space.

Individual's spaces are private spaces assigned to every learner (Motivation and Requirements xi, *Personalisation*). Such a space is accessible to the owner only. She can manage (i.e. create, edit, delete) all her data according to her needs and preference. She can copy contents from public and group spaces (of which the owner is a member) to her individual space and can also share her data with other individuals, groups or public spaces.

The *teacher's space* is also an individual space with special rights. The teacher's space would also provide support for creating new contents, assessing learners' work and providing feedback to them (Motivation and Requirements vi, *Scaffolding*).

Group spaces are the working spaces for groups of learners who are working together on some collaborative task (Motivation and Requirements iii, *Collaborative learning*). Such a space is accessible to only the members of a particular group. They can all create, edit and delete the contents of their space.

All these logical spaces are stored on a server. Figure 1 shows the logical division of these spaces and their users.

b *Physical model*. The logical structure describes the space and rights of the learners and teachers. This seems simple, but one has to account for the fact that there are multiple technologies involved in this framework. Learners may want to access and communicate between these logical spaces while working on different devices. For example, a learner may want to check the next class schedule through his mobile device while travelling in a bus or may want to access her individual space and copy some contents to the group space while working on a group task on a multi-touch table (Motivation and Requirements ii, *Usefulness in multiple situations*). Leaving all the required data transfer and synchronisation between devices and logical spaces on the learner's behalf is tedious for them and constitutes a disruption of learning activities. So there should be some automated synchronisation processes between logical spaces and devices as shown in Figure 2.

All the devices used in the learning platform have wireless connectivity in the form of Bluetooth, Wi-Fi and 3G. So when learners are in their classroom with their mobile devices with Bluetooth connection turned on, the system will do an automatic synchronisation between individual's, group and public spaces via 3G, Wi-Fi or Bluetooth, and as soon as a change is made to these spaces, it would be immediately available to all its users via any device (Motivation and Requirements x, *Immediacy*). For example, a group of learners working together, saves their work on their group space and may copy it to their individual spaces using the laptop computer and then check the same file on their mobile device. Right after that, they will (and should!) see an updated version of the file without any explicit refresh or reload action.

Figure 1 Logical structure of the communication: the public space is accessible to all participants of class, individual spaces are accessible to owners only, while group spaces are accessible to all members of that group (see online version for colours)

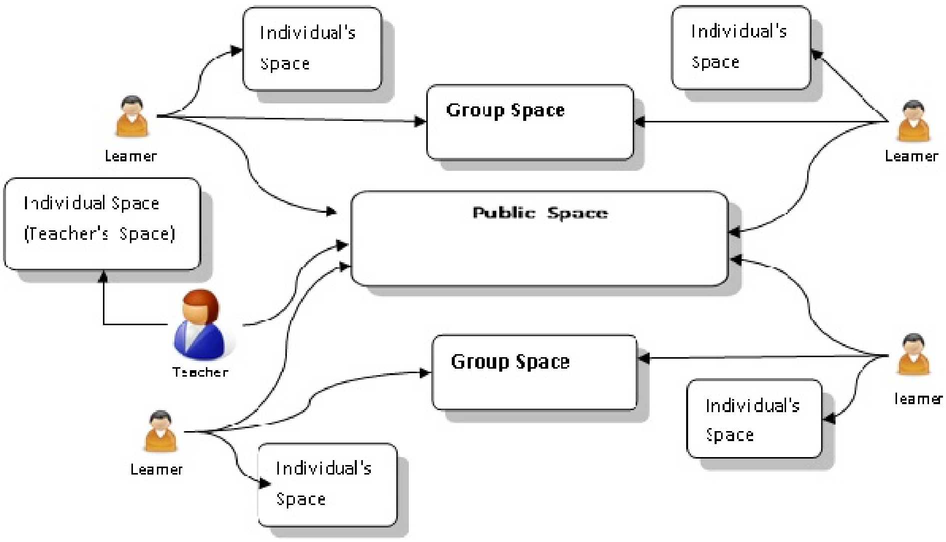
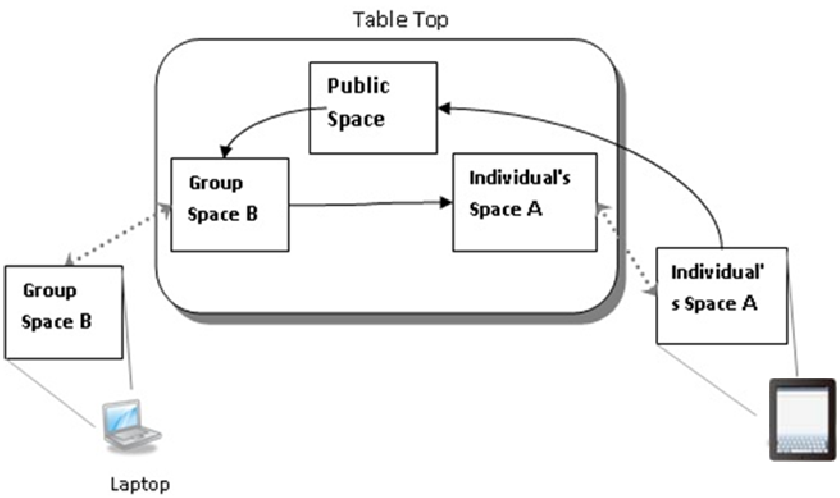


Figure 2 Synchronisation and user-intended data transfer. Dotted lines represents synchronisation, while solid lines represent user-intended data transfer



When learners are outdoor for fieldwork or in their homes, the synchronisation will be performed through the internet via 3G. If a learner loses internet access due to some reason and makes changes to her data, these changes will be saved in her individual's space and when the connection is available again, the system will synchronise.

An important distinction in the context of all these data transfer activities between logical spaces and devices needs to be made between *synchronisation* and *user-intended data sharing*. Synchronisation is the automatic process, performed by the system, to keep data up to date in different logical spaces regardless of the devices through which it is created or edited. Data sharing, on the other hand, is an activity that a user might want to perform. For example, a learner notices something (an article or a picture) that might be of interest for her fellow learners in her citizenship class, so she puts that data on the public space of the citizenship class. Another learner finds that data useful for her group assignment and copies it from the public space to their group space via the multi-touch table. These two data transfers are examples of user-intended data sharing. On the other hand, when the members of the same group access their group space, whether from their mobile devices in the classroom or from their laptops at home, they will see the same data. That is the synchronisation done by the system.

Figure 2 shows these two data transfer activities, where dotted lines represent synchronisation and solid lines represent user-intended data transfers.

4.3 Software

Software applications to be used within this framework have to consider some criteria with respect to two important factors, *device independency* and *domain independency* (Motivation and Requirements ii and vii). The framework uses specialised technologies for specific tasks. For example, mobile devices would be excellent for data collection but might not be the best choice for data manipulation. On the other hand, a multi-touch table is probably never going to be used for data collection in the field, but would be superb for collaborative data exploration and manipulation. Some tasks, however, should be doable regardless of the hardware platform, like viewing or sharing data. So, to fulfil the need of *ubiquitous access* and *usefulness in multiple situations* (Motivation and Requirements i and ii), some applications within the framework will be specific for particular technologies (like a toolkit for mobile devices for data collection and a toolkit for multi-touch surface for data manipulation), while other applications would be designed to run on multiple technologies, like reading or sharing files or accessing message boards. On the other hand, some features are available on all kinds of devices like text editors, picture galleries and Bluetooth connections.

In addition to this dimension of device dependency vs. independence, the learning contents and tools will differ by subject too (Motivation and Requirements vii *Adaptation*): for an English class, they could not be exactly the same as for geography or citizenship learning classes. These classes will share some common tools like a text editor which will be necessary for all the domains, but a map manipulating toolkit or an equation editor might not be needed in the English class. Keeping these factors in mind, the software to be used within the framework can be categorised into four classes with respect to devices and domains.

Device and domain independent. Some tasks are common in multiple domains and should be doable through any device like reading text, viewing a picture or playing audio and video, reading messages on a board or sending messages to other learners or teachers. So application support for these kinds of tasks is needed on all devices and in all domains.

Device dependent and domain independent. This class of applications covers tasks that are feasible for some devices but not for all (like collecting data through mobile devices on a field trip), regardless of the domain, as fieldwork is possible in many different domains.

Device independent and domain dependent. This class of software covers domain-specific learning contents and some data manipulation toolkits (like an application for voting in the citizenship learning class or a map reading or GPS data manipulating toolkit for the geography class) regardless of the hardware platform.

Device and domain dependent. This class consists of tools that are both domain-specific and device dependent. For instance, in a geography class, learners may view a task-specific map through any device, but can only manipulate it using a specific application on the multi-touch table. Table 1 summarises some tasks from the learning scenarios with respect to both their device and domain dependencies.

Table 1 Task categories according to device and domain dependency for application development

	Device independent	*Device dependent*
Domain independent	View data (reading text file, playing audio and video, viewing pictures) Share data Communication (messages, notice board, class schedule) Text editor	Data collection Making videos Recording voices Taking text notes Collaborative task Making presentation Taking photos
Domain dependent	Voting Developing learning material Reading map	Assessing GPS Assessments Working on map

Teacher's toolkit. In addition to applications as classified by devices and domains, there is another important software function: providing a platform for the teacher to help her develop learning contents, assignments and exercises for students and for assessing students' works. The system must help the teacher adapt existing learning contents and develop new contents.

5 Prototype system

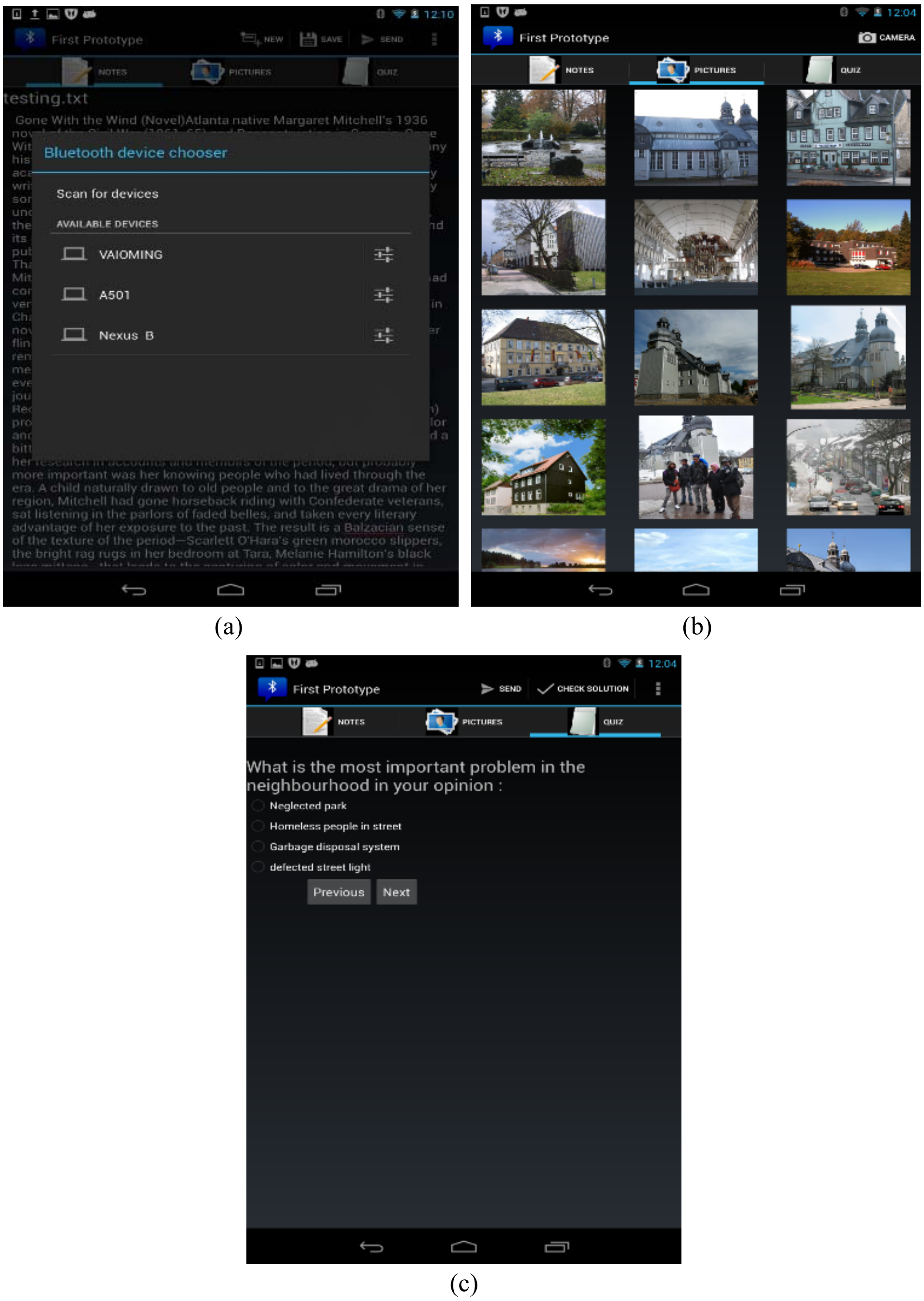
Based on the described framework, a prototype application has been developed. First, we describe the basic architecture of the system in Section 5.1 and then explain its utility through an example scenario in Section 5.2.

The prototype allows various devices (tablet PCs, laptops and multi-touch tables) to connect through Bluetooth and exchange data (currently texts and pictures and quizzes). Users can create text files, take pictures, take part in a quiz and share data with others.

5.1 Architecture

The prototype system is heterogeneous in terms of implementation platforms and hardware devices. The system comprises a desktop application and a mobile client, which runs on Android. The desktop application supports desktops, laptops or multi-touch tables with Windows 7.

Figure 3 Screenshots of application on Android platform. (a) Notes section; (b) pictures section; (c) quiz section (see online version for colours)



The application has been developed using the Eclipse IDE with the Android Development Tools (ADT) plug-in for the Android side and the WindowBuilder plug-in for the desktop side. Android SDK and emulators are necessary too for application development. The interface design of the Android application has been optimised for Asus Nexus 7.

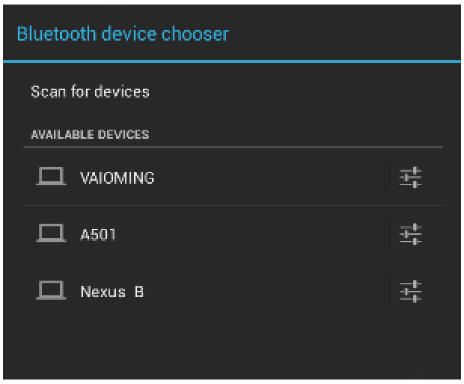
The mobile client running on tablet PCs consists of three sections:

- Notes
- Pictures
- Quiz.

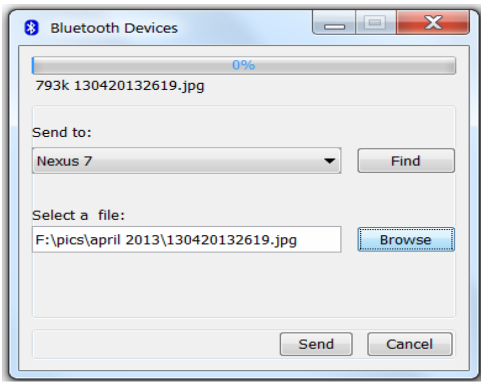
The *Notes* section provides a text editor for creating, editing and viewing text files. The *Pictures* section provides a picture gallery and allows the user to use the device camera to take pictures. The *Quiz* section presents the user with a quiz sent by the teacher via Bluetooth. Users can solve the quiz, send it back to the teacher and can view his/her score in the quiz. Data from all three sections can be exchanged via Bluetooth with other users. For file transfer via Bluetooth, the application employs Android Intent. Figure 3 shows some screenshots for the tablet application.

The desktop application comes with a text editor and a picture gallery and a Bluetooth file transfer facility too. It is a Java-based application. The interface is designed using Java SWING. BlueCove libraries have been employed for Bluetooth services on the desktop side. Figure 4 shows Bluetooth connection facility for both tablet computers- and windows-based devices and Figure 5 shows the screenshots for the desktop application.

Figure 4 Screenshots of device and file selection window. (a) For tablet computer; (b) for desktop/laptop or interactive table (see online version for colours)



(a)



(b)

The system also provides an application for teachers to make multiple-choice questionnaires for learners. The application allows for designing new questionnaires, editing them and sending them to learners' tablet PCs via Bluetooth. Figure 5(b) shows screenshot of the application for designing questionnaires.

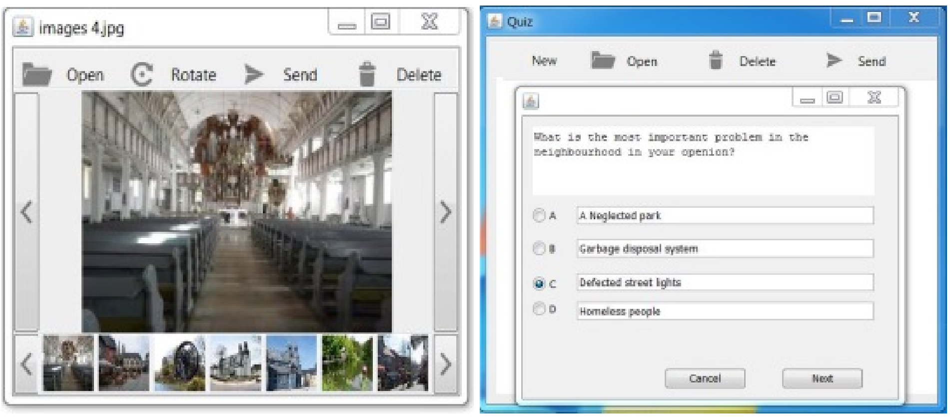
5.2 Learning scenario

Let us understand the utility and effectiveness of the proposed system through an example of learning scenario adapt from Teachit Citizenship (http://www.teachitcitizenship.co.uk/rights).

A citizenship teacher decided to engage her students in a way so they can develop a better understanding of their community and to appreciate the facilities the community offers to them. Therefore, she selects an area of radius 2 km around the school and divides that area between small groups of students. Then she asks the small groups equipped with tablet PC Nexus 7, running the prototype system, to take a tour through their assigned area and gather data about all the good and bad aspects of the neighbourhood. For example, they need to notice important places, organisations and institutes. What are the recreation facilities in that area? What are the major businesses there? What kind of shopping places, health facilities, schools, parks, churches and other institutes are there? They also notice cultural variations, different authenticities and age groups. All such things count as *assets* of the society. During that tour, students are also asked to identify the problems of the community (e.g. maybe they notice many homeless or addicted people in the streets, a neglected park or any other things that they feel need attention). Such things count as *needs* of the society. Students gather their data in different forms. They take pictures, talk to people and conduct small interviews, take text notes, using their mobile devices. Figures 3(a) and 3(b) show text notes and pictures collected by learners on their trip.

After coming back to the class, they share all of their collected data on a multi-touch table through Bluetooth. Figure 4 shows Bluetooth connection facility for both tablet computers and desktops, and Figure 5 shows the picture gallery and quiz design interface for desktops. Then the teacher asks them to separate assets and needs in two different sections and arrange them.

Figure 5 Screenshots of system on desktop. (a) Picture gallery; (b) quiz window (see online version for colours)



(a) (b)

So students arrange their data in some presentable form. For example, they put together all the data (e.g. pictures and text) about a particular park as assets. They edit their text notes, arrange pictures in some specific patterns and drop some data such as multiple pictures of the same thing. They are also asked to add issues in their table of assets and needs that they might not have observed during their trip but has been in their knowledge by other sources. For example, a friendly shopkeeper, or a resident who is very active for the community, would count as asset and a patient or an elderly person feeling lonely would be considered as a need.

After this, the teacher could engage her students in a discussion about their findings in multiple ways. For example, she asks them about the issue in the needs section that they think is most important. The teacher sends a small questionnaire to students' tablet PCs through Bluetooth, asking the most important problem in the neighbourhood. Figure 5(b) shows screenshots of application for designing questionnaires and Figure 3(c) shows the quiz appearing on the learners' tablet computers.

The data is then rearranged according to students' feedback and students are asked for suggestions on how to address the particular prime need. All suggestions are collected and placed next to that need. As an alternative, the teacher could ask what aspect of their neighbourhood the students like most and want to explore more. A file, containing the contributions of the whole class, is transmitted to the students' handheld devices along with another questionnaire asking which project they want to work on. They give their feedback about their preference of certain issues they like to proceed in future by solving the questionnaire and sending it back to the teacher.

The result of this exercise is displayed on the multi-touch table. Now the teacher puts her students to work more closely in groups on their selected issues. For example, five students selected a neglected park in the neighbourhood they would like to revive, or two students select a patient whom they want to help. In the assets section, three students select a Chinese community centre they would like to explore more. Now each issue is discussed one by one. For example, everyone is asked for suggestions on how to help improving a particular park. Everyone gives their suggestions (again, either through their handheld devices or directly on multi-touch table). All suggestions are collected and displayed on the table and their feasibility is discussed. Some possible suggestions are as follows:

- Write a letter to the local authorities.
- Contact the caretakers of the park and offer to help.
- Start a campaign to attract other people to the issue.

After that, a plan is devised and the groups discuss how they will carry on their task for the whole term. In regular meetings, every group presents their accomplishments.

At the end of term, every group presents the outcomes of their projects. For example, a group working on reviving the park presents how they have helped improve their parks by showing pictures before and after their projects. Another group presents their finding about the Chinese cultural centre with pictures and interviews.

6 Discussion and future work

In this paper, we described a novel general framework that combines the advantages offered by different state-of-the art technologies for learning indoor and outdoor. Integrating specialised devices for different learning activities in a common framework provides an environment in which learners can benefit from the facilities provided by different technologies while avoiding the trouble of switching from device to device when they engage in multiple, interlinked learning activities. A pilot system based on this theory has been implemented and presented in this paper, which allows learners to collect data on field trip through tablet PCs and share it with his/her peers via Bluetooth. Furthermore, the system also lets teachers to design and send quizzes to learners' tablet PCs and get their solution back via Bluetooth.

We described the system architecture and the main components of the application and illustrated its utility using typical classroom activities and fieldwork scenarios. On the hardware level, the system supports classroom technology like interactive whiteboards and multi-touch tables, field technology like tablet PCs and home technology like desktops and laptops. The framework provides a smooth communication and synchronisation between these devices. On the software level, we classified applications with respect to devices and domains.

The potential of multi-touch tables for presenting shared views to a group of learners and enabling them to perform simultaneously shows a lot of promises for collaborative learning. But the collaboration mechanism around the table needs to be carefully investigated. For that purpose, we need meaningful applications for real learning scenarios. One simple way is to adapt the applications from other interface types. Adaption can be of great help for understanding new interfaces. It provides a basis for design, can reduce development time, provides a point of comparison and eventually facilitates evaluation. However, adaption alone could not realise the full potential of multi-touch tables. We also need to explore what kinds of learning activities can specifically benefit from them. That will allow us to conceive and design new learning activities.

Moreover, the role of mobile devices for in-class tasks will be explored in more depth. Mobile devices have not only proved their usefulness for fieldwork and data collection, but their wireless connectively is of great value for certain kinds of in-class activities too (e.g. quick feedback, voting). In the future, we will utilise this feature for indoor learning activities.

Using multiple devices within learning sequences implies better support for specific requirements. But it also poses the risk of overdependence on a particular device. To avoid this risk, a flexible usage should be possible on all participating technologies. Some cases are more likely than others; for example, a multi-touch table would probably never be required on a field trip. But in a classroom, tablet computers or desktops or laptops could possibly replace the multi-touch table. This is the reason why we take into account the *device*/*domain dependence* matrix (Table 1) for software development. To correctly categorise any learning activity in this matrix, we will work in close collaboration with teachers and make sure that proper support is available in as many situations as possible.

Moreover, right now our system can only facilitate user-intended data transfer using Bluetooth. In the future, the communication structure will advance in two directions. First, a synchronisation mechanism will be incorporated in the system so that user-intended data transfer and synchronisation of data for a particular logic space, across various hardware platforms, can be distinguished. Second, other wireless communication (WiFi, 3G/4G) will be incorporated into the system. Furthermore, resource development and management for both teachers and learners will be improved.

7 Conclusion

We present a novel generic framework, capable of connecting different kinds of devices (including tablet PCs, laptops and multi-touch interactive tables) such that the most suited device is employed for a specific learning activity. A prototype based on this idea which enables learners to collect data in the form of text and pictures and share it with heterogeneous devices using Bluetooth has also been discussed in this paper.

The next steps in our research include pilot tests with the system prototype, exploring multi-touch table's features and utilities of mobile devices for in-class activities as well as incorporating more communication features.

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