ColInq: A System for Collaborative Inquiry Learning with Mobile Devices

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Abstract

In this paper, we explore the notion of seamless learning by presenting the design and development of the ColInq (Collaborative Inquiry) system, a mobile application designed to help students continue their collaborative inquiry learning across multiple contexts and platforms. The ColInq system is grounded in the theories of inquiry learning and collaborative learning where learning is viewed as a progressive and collective inquiry process. ColInq allows users with mobile devices to manipulate multimedia content, take notes or create inquiry questions in the course of inquiry learning. Created multimedia resources are then stored onto the centralized server for online collaborative learning. The mobile client-side application is built with context-awareness in mind, using GPS and CellId information. We conclude the paper with the application of the ColInq system in the context of mobile learning trails, and discuss pedagogical implications and some areas for further improvement.

Keywords*: mobile application, location-awareness, inquiry learning*

1. Introduction

One of the challenging issues in today's education is wide breadth but low depth of knowledge [1]. Further, school knowledge is often characterized as de-contextualized and abstract; hence, students have difficulty seeing the connection between school knowledge and real-life applications. Recently, various technological solutions such as mobile devices and web 2.0 tools have been hailed as possible solutions to this issue by providing more situated experiences, helping students apply their knowledge in real contexts, and interacting with authentic environments for situated experiences. Mobile devices can be used to organize data collection and analysis in real-time without much time delay [2]. Prior research has shown that when learning process is organized in this synchronous and seamless way, students can make strong connections between ideas and observations, and between abstract and concrete knowledge [1]. For example, de Jong, Sprecht and Koper suggest a model of contextual Internet diaries using blogs where content is defined on mobile devices [3]. Pierroux looks into the combination of wiki pages, Internet diaries and mobile applications that integrates learning experiences and outdoor environments (e.g., museums) [4]. Similarly, So, Seow and Looi suggest integrating Google Maps into field trips to support collaborative knowledge building in-situ [1].

In this paper, we extend this notion of *seamless* learning further by presenting the design and development of the ColInq (**Col**laborative **Inq**uiry) system, a mobile application designed to help students continue their collaborative inquiry learning across multiple contexts and platforms. Pedagogically, the ColInq system is grounded in the theories of inquiry learning and collaborative learning where learning is viewed as a progressive and collective inquiry process. By employing graphically attractive and ergonomically sound user interface design, the ColInq system allows users with mobile devices to manipulate multimedia content, take notes or create inquiry questions to be answered in the course of inquiry learning. Created multimedia resources are then stored onto the centralized web server so that learning process can be continued online where students can share collected artifacts and ideas with peers, discuss topics, and continue their research on subject of inquiry. The mobile client-side application is built with context-awareness in mind, and uses GPS (Global Positioning System) and CellId (Cell Identification) information to locate users and adjust user interfaces. Moreover, location information is incorporated into Google Maps to provide users with more interactive location-based learning experiences.

In this paper, we describe ColInq's client-server system architecture, application data model, and the way multi-threaded tasks and temporary file storage are handled within the system. We also present the mobile client-side application consisting of the four main modules (i.e., pictures, videos, notes and inquiry questions) that communicate with the server-side web services to store data on the server and to fetch GPS coordinates depending on CellId codes. We conclude the paper with the application of the ColInq system in the context of mobile learning trails, and discuss pedagogical implications and some areas for further improvement.

2. Collaborative Inquiry Learning with Technology

Inquiry learning is a student-centered, active learning approach focusing on questioning, critical thinking, and problem-solving. Although there are different definitions of inquiry, it is generally agreed that inquiry learning consists of at least four important stages: *generating hypothesis*, *collecting data*, *interpreting evidence*, and *drawing conclusions*. Prior research suggests that inquiry learning enhances students' critical thinking, problem-solving skills, ability to explain data, and understanding of concepts [5].

Various technologies have been used to support students' inquiry learning. Recently, there has been increasing interest in the potential of mobile technologies and Web 2.0 applications for supporting and sustaining inquiry learning. Mobile technologies are becoming more embedded, pervasive and connected in students' daily life with enhanced capabilities for rich social interactions, context awareness, and Internet connectivity [6]. The affordances of mobile technologies for supporting inquiry learning include:

- *Portability and mobility*: Mobile technologies allow students to transcend geographical limitations to work continuously even as their location changes.
- *In-situ experiences*: Mobile technologies enable users to collect data and analyze them in-situ [7].
- *Location-based experiences*: Mobile devices can be used to gather and respond to information specific to the current location, environment and time. For example, students can refer to their device for stored information or resources or do a new search whenever their curiosity prompts them to do more inquiries [8].
- *Democratization*: The affordability of mobile technologies has the potential to democratize access to information.

Inquiry learning process with mobile devices can be enhanced with the integration of collaborative learning aspects. With collaborative learning, the members of a group are encouraged to help each other to achieve the shared goals of learning, thereby improving individual learning as well. Rather than relying on teachers and textbooks as sources of knowledge, students can conduct their own inquiry and share what they have learned with other classmates.

Based on the literature surveyed, however, we find that broadly speaking, most mobile applications are not designed for education, especially in terms of supporting inquiries in situ and fostering collaboration. There is a lack of well-integrated and open mobile solutions to organize, search and share data within certain groups of students. Even if we explored within the limited range of education-based mobile learning tools that are available, we find that they are too location and content specific. These heavily contextualized applications render it difficult for learners to use them in cross-contextual situations. These constitute a compelling reason for us to search for a solution, such as the coupling of mobile, web 2.0 and location-aware technologies, to alleviate these problems. To integrate inquiry learning and collaborative learning effectively in a mobile learning system, a *collaborative inquiry learning* model is proposed for the design of mobile learning applications:

- *Phase 1 Experiential and Exploratory Stage*: Students begin inquiry process by experiencing and exploring the environment. Then they reflect upon the problems raised in the environment, forming their own inquiry questions to pursue.
- *Phase 2 Individual Inquiry*: Students collect and share data by using mobile technologies. Data include pictures, videos, field notes and questions created in-situ.
- *Phase* 3 *Collaborative Inquiry*: Students search online resources or their peer's data and look for the evidence verifying their inquiry questions. In this stage, collaborative learning is emphasized to promote interactive learning processes among learners - data sharing, idea sharing, and discussion.

3. Technologies Used by the ColInq System

3.1. Location-based Technologies

GPS is a global navigation satellite system that provides constant uninterrupted and reliable information about time and space, independent of metrological situations for every location with clear sky view that can be reached by at least four GPS satellites [9]. GPS is accessible to every person with an adequate GPS receiver that calculates the position by employing a precise method of measuring GPS signals received from the satellites.

GMS Cell ID is a unique number used to identify a single base transmitter station (BTS) or BTS station sector within a local code area if not within a GSM network [10]. There are a couple of both free and commercial web services that can convert Cell IDs into a geographical location of the transmitter. One of such services is OpenCellId that can be used to fetch GPS coordinates with CellId information if there are significant numbers of transmitters. This is an open source project with an aim of assembling a database of CellId numbers of all transmitters with their geographic locations [11]. The official webpage (http://www.opencellid.org/) describes the programming interface used to access the service through an HTTP service by supplying the following four parameters: (1) MCC - *Mobile Country Code*, (2) MNC - *Mobile Network Code*, (3) LAC - *Local Area Code*, and (4) CellId – BTS identification.

Google Maps is a cartographic web oriented service which allows different representations of geographic maps including satellite and road displays, various tools for route planning as well as searching points of interests (e.g. institutions, restaurants, gas stations etc.). Google Maps can be integrated into an existing application by using Google Maps API [12] that is a programming interface that can be accessed through the HTTP GET requests in order to retrieve the map of a location. Map size and other parameters can be specified as a part of the HTTP GET request.

3.2. Model View Controller (MVC)

Model View Controller (MVC) is a design pattern created during the 1970s in the Xerox PARC laboratories for the use with the Smalltalk programming language. It was designed to separate programming codes which represent a business logic of the problem from programming codes which present a problem to users; therefore allowing more agile development, maintenance, testability and reusability of software. There are three roles in the MVC design pattern:

- *Model* – contains data and behaviour which present problems (domain models) and rules that allow access to data and its modification
- *View* – displays the current state of the Model to the user
- *Controller* – processes users' actions and changes the state of the Model by calling adequate methods

There are many instances of the MVC approach (e.g. Model-View-Presenter) but all of them boil down to a similar general sequence of events (Figure 1): (1) User uses the application and sends events to the View; (2) Controller processes the event and translates the interactions with the View into the actions that are done into the Model; (3) Controller calls the methods within the Model that might change its state; (4) After the Model state changes, View generates new user interface; and (5) User interface awaits of further user activities.

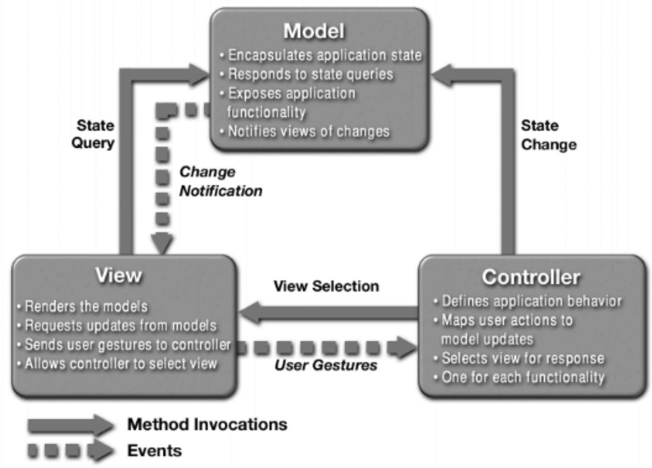

Figure 1. Model (M) – View (V)-Controller (C) model

4. System Architecture

4.1. Main System Components

ColInq was designed with the following aims in mind:

- It should be able to capture information on-the-fly with a mobile device and to automatically store it for future retrieval
- It should be able to provide continuity in diverse learning experiences through a web 2.0 application
- It should be able to promote social interaction and encourage further probing of certain topics through a web 2.0 application.

The system architecture of Collnq is depicted in Figure 2 that shows three main components of the systems: (1) Mobile data collection tool (an application installed on students' mobile devices), (2) Web 2.0 application for the retrieval and organization of collected data for collaboration and online discussions, and (3) Web services used to accept, store and fetch data.

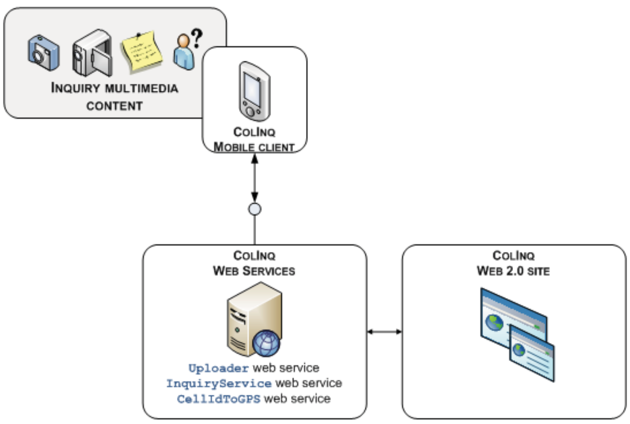

Figure 2. ColInq system architecture

The mobile client side ColInq application uses two main ways of locating users: GPS signal and CellId codes. Location information is then used to achieve location-awareness in the system in various ways such as showing current user's location on the Google Maps integrated into the main application screen on the device. The other use, perhaps more important, is related to tagging multimedia objects with location information before they are sent to the central server repository. Thanks to location information, digital resources can be combined with the Google Maps and shown on the web application available to users. In Figure 3, the left area shows the list of multimedia content transferred to the web application, while the right area shows pins denoting the exact locations of the gathered content.

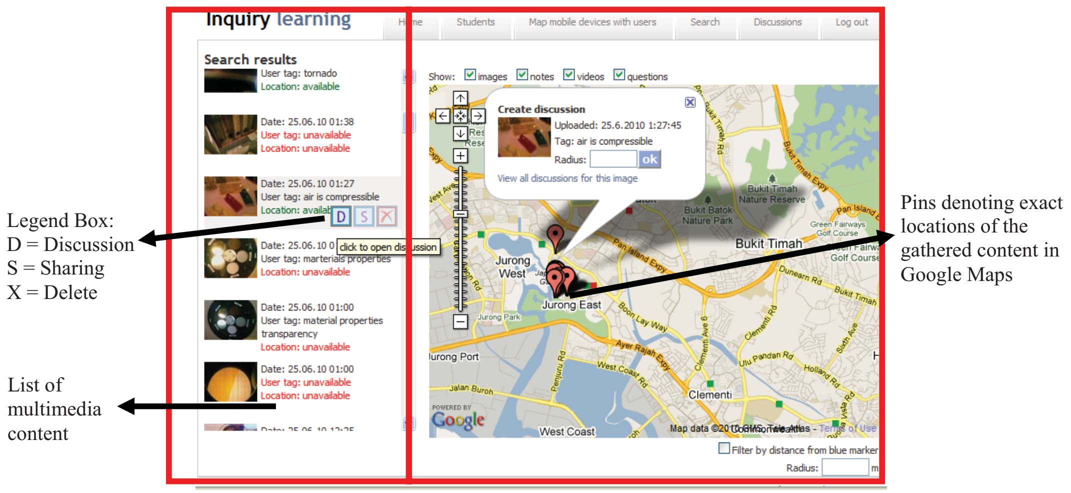

Figure 3. Web application for collected multimedia content and location

4.2. Mobile Data Collection Tool

ColInq mobile client-side application is used to store and fetch inquiry learning content. The application is typically used by students to collect multimedia content that is temporarily stored onto a mobile device. Once the mobile client side application is running, the user is presented with the main application menu from which inquiry data collection tools can be accessed (Figure 4). With this application, students can capture and create the following multimedia content: images, videos, drawings and inquiry questions.

Figure 4. Main menu for data collection

The central part of the main application screen is reserved for a Google map showing current user location. The map contains custom navigation arrows (upper left hand side of the map) that allow students to explore surrounding location areas. The bottom row consists of icons used to open the following modules (from left to right): (1) picture taking and annotation module, (2) video taking module, (3) drawing module and (4) inquiry questions module. In this paper we cover only the picture taking and annotation; and inquiry questions modules since they have some functionality in common with the remaining modules.

4.2.1. Picture Taking/Annotation Module and Inquiry Question Modules

The first icon the left hand side of the main application menu indicates mobile device's built-in camera function for data collection. Once the button is clicked, it transfers user choice into the system API call through the `CameraCaptureDialog` class and sets various parameters such as the size of the picture and the ratio of its width and height. After capturing and scaling, the taken picture is rendered to a user and displayed with the annotation module shown in Figure 5. The user can use the module controls to pick a color for annotation, annotate a picture taken, clear any existing annotations, and tag the drawing. Once the save button is clicked, the annotated picture is handed over to the `FileManager` module to be sent to the server side data storage and, eventually, be rendered through the web 2.0 application of the ColInq system.

Figure 5. Picture annotation tool

Figure 6. Inquiry questions tool

The inquiry questions module allows users to enter questions consisting of a question body and a tag which is used as a search parameter at subsequent retrieval and browsing sessions. As shown in Figure 6, the right hand side of the picture demonstrates the use of the integrated keyboard which is especially important for devices without physical keyboard.

4.2.2. Managing Binary Resources

In the event of low network connectivity or temporary server repository unavailability, the multimedia inquiry items created by users will be temporarily stored onto the mobile devices. As soon as the connection is established or the distant server storage becomes available, the files are to be handed over to the server and deleted from the devices. To encapsulate the described functionality, the `FileManager` class was created as shown in the class diagram in Figure 7. `FileManager` attempts to send all files to the server-side storage periodically. The file sending period has to be determined to keep the number of Internet re-connection attempts reasonable as to resource utilization (e.g. battery life). Empirically, for the normal operation, the constant was fixed to 10 seconds. In the event of network connection failure, an adequate message will be displayed to users as the two icons in Figure 8 indicate.

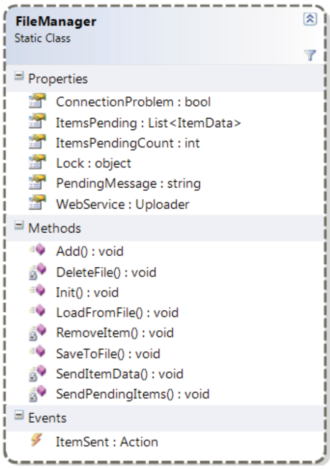

Figure 7. FileManager class for managing binary multimedia inquiry resources

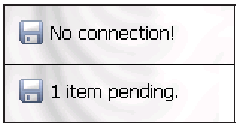

Figure 8. FileManager class for managing multimedia inquiry resources

Binary resources not being sent to the server side are stored into device's local memory and are being tracked by an XML file `pending.xml` as shown in the following code snippet 2.

pending.xml data repository list

```
<?xml version="1.0" encoding="utf-8"?>
<pending>
 <item type="picture"
      id="9c3bc6b1-f60a-44a3-8fbe-4286f9760943"
      cellId="0,0,195,0"
      gps="47.6336216666667,-122.186456666667"
      tag="Anna in Ljubljana..."
      time="2010-06-11T19:34:26-07:00" />
 <item type="video"
      id="8fad3a96-fa32-421a-826b-fa09f7113c27"
      cellId="0,0,195,0"
      gps="47.6336216666667,-122.186456666667"
      tag="Sun on the west"
      time="2010-06-11T19:35:19-07:00" />
 <item type="note"
      id="92d94ecc-ad1e-4102-9a2f-aeea1fa9cece"
      cellId="0,0,195,0"
      gps="47.6336216666667,-122.186456666667"
      tag="Instructions for approaching building"
      time="2010-06-11T19:35:42-07:00" />
 <item type="inquiry"
      id="2517b3de-c779-4335-831b-c9af10493cb4"
      cellId="0,0,195,0"
      gps="47.6336216666667,-122.186456666667"
      tag=""
      time="2010-06-11T19:36:04-07:00" />
</pending>
```

4.2.3. A multi-threaded approach to designing the mobile client-side module

To allow for the uninterrupted operation of the mobile client-side application, the workload was divided into separate threads (units of work) so that the user interface thread remains unblocked and the system remains responsive. Figure 9 presents the work division according to the threads that deal with separate units of work.

In the ColInq client side application, each Google Maps retrieval is modeled as a separate asynchronous thread call as well as the extraction of the CellId information. If the GPS coordinates are not known, a new synchronous web service call is spawned to convert the CellId identification into GPS coordinates. Since the management of the binary resources should not disrupt the continuous operation of the user interface, the File thread is used. Inquiry questions get fetch via the `InquiryService` web service in another separate thread.

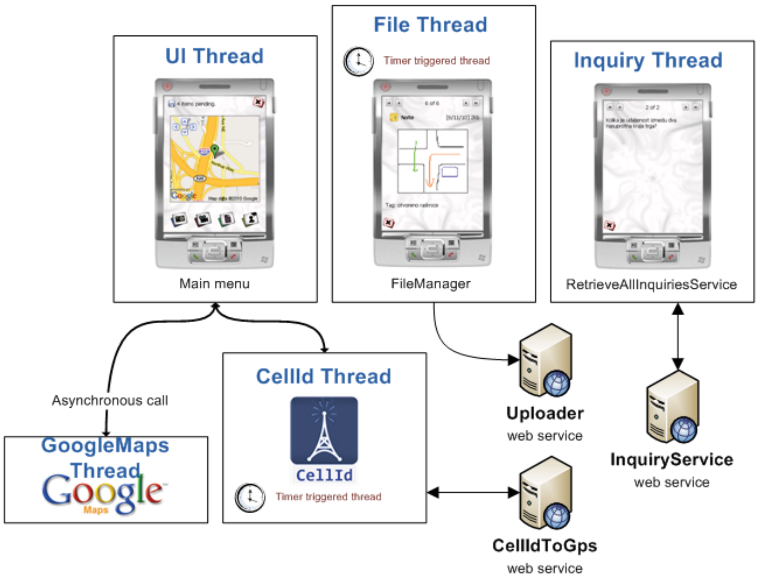

Figure 9. Threads managing the client side operations

4.3. Web 2.0 Application

The web application consists of the two main parts: client-side and server-side. The server-side part is implemented in ASP.NET MVC technology, which is Microsoft's implementation of the MVC design pattern. After logging onto the system, a user is presented with the login screen. Depending on the user role, different user interfaces (teacher view vs. student view) are rendered to allow users to access relevant functionalities presented in Table 1.

Table 1. System roles and available functionalities

Teacher	Student
• Log overview • User management • Relating users to mobile devices • Overview of all stored multimedia content • Content sharing between users • Online discussion • Searching content according to time, types, tags and users	• Overview of own content • Sharing of own contents with other users • Online discussion • Searching own content according to date, types and tags

One of main affordances of the application is searching and accessing content stored in the database. The content can be searched according to several parameters: content types (videos, images, questions and notes), user names, time (filtered by start and end dates) and tags assigned by users at the time of creation (see Figure 10). The search results are then depicted in a form of a web page with a list on the left hand side and a Google map on the right hand side (Figure 11).

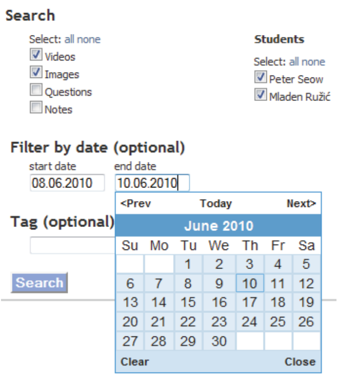

Figure 10. Search functions

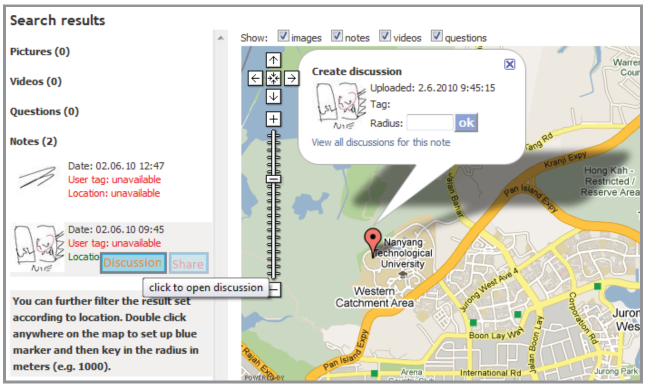

Figure 11. Two-dimensional representation of the retrieved content

The Google map space shows all stored multimedia data with its collection spot GPS/CellId coordinates and is used for easier orientation, visualization and content filtering. Six main parts of the Google map component can be identified as follows: (1) content filtering tool; (2) navigation and zooming tool; (3) position identification pins; (4) popup balloons containing more information about gathered multimedia content; (5) map-based radius filtering tool; and (6) marker tool to be used in the combination with (5) (Figure 12).

Figure 12. Six main components of Google Maps representation of search results

As users hover the contents of the search result list, two main buttons are rendered: Discussion and Share. The choice of the Discussion option results in redirecting users to a separate discussion page as shown in Figure 13. In case there is no existing discussion around the chosen multimedia content, a new discussion will be automatically opened. With the use of the Share button, students can share the contents with other students and make it visible within their search results.

Figure 13. A discussion opened around three types of inquiry learning multimedia content (eight pictures, one question and one note)

4.4. Server-side Web Services Custom API

The mobile client-side application uses some specifically designed as well as some publicly accessible programming interfaces such as Google Maps API. Figure 14 presents three web services created for this application: `CellIdToGpsConverter`, `Uploader`, `Uploader and InquiryService`.

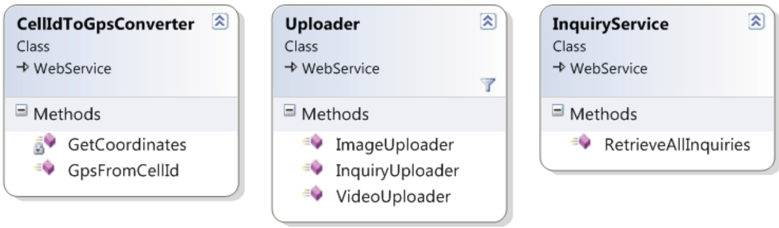

Figure 14. The three custom designed web services used by the mobile client-side ColInq application

`CellIdToGpsConverter` web service is accessed whenever the `CellId` code of the base mobile station has to be interpreted. If GPS coordinates are available, this service is not used since that would generally imply less accurate location information offered to users. `Uploader` service is used to store created multimedia resources into the server side storage. Its parameter `timeDeltaSeconds` is used to neutralize the difference between the time of resource creation (on the client-side) and the time of storage (on the server-side). `InquiryService` web service is used to fetch inquiry learning questions students created on their mobile devices onto all other student mobile devices, therefore facilitating collaboration in-situ.

5. Field Testing and Preliminary Findings

Collnq is designed and developed to foster in-situ inquiry or capture in-situ experiences marked by time, space, and artefacts. Students are engaged by in-the-moment interest known as "situational interest" [13] when they are interacting with the environment. Examples of situational interest include the spark of momentary interest when students observe a phenomenon related to a Science Centre exhibit, listen to an interesting talk or having a unique experience. Students piqued by their situational interest may explore further to develop it into a stable and sustained interest [14]. For example, after watching a documentary on Sharks, the student may embark on research about sharks to find out more about the different species, habitat, anatomy or conservation efforts. Students may want to capture experiences they encounter which can be planned or emergent in nature [15]. Such moments are important since it may be meaningful to them at that moment and linked to their prior experiences to construct new understanding or meaning.

Using ColInq on the Smartphone, momentary interest or experiences can be captured with images, videos, drawing or text. The events can be tagged with keywords which reflect the students' interest or experiences. These tags could subsequently be used as proxies for students to search information using attributes such as events, interests or experiences. If GPS data location of the place is available to the Smartphone and ColInq application, the event will be tagged with the geographical information. Students may log into the Web 2.0 ColInq environment to review the moments of interest or experiences they have captured with the artefacts such as videos, images, drawing or text, and the location position. They may choose to share them so that others can view and comment on them.

ColInq can be used during mobile learning trails to connect out-of-school learning experiences with in-school lessons, share individual learning experiences, and create collective experiences. To study how students use ColInq outside the school context, we followed students on fieldtrips to a Chinese heritage site and science museum to understand how they used the application for sense-making.. At both sites, the students captured their experiences as they interacted with the environment using ColInq. They can use the Smartphone to snap an image or record the video, draw a picture or write text to capture their experiences. Examples of the experiences include an image of an old shop, a video of a guide explaining to them about the place, or a drawing of an artefact they saw during the trip as well as writing of fieldnotes with the drawing module. The individual experiences were recorded by the students on ColInq and uploaded to the server. For activities conducted outdoors, the GPS data of the experiences was also recorded and uploaded. As a post-lesson activity in school, students can use ColInq to recreate the collective experience of the trip from the various places visited by individual students. The students can share their experiences by using probes such as images, videos, drawings or text notes. The location of the places visited by the students can be viewed on a map provided by the uploaded GPS data. The map of the outdoor activity and geographical position of the landmarks that was visited by students can provide rich contextual information about the significance of the place and resurrect the students' experiences. On ColInq, students can create discussion based on the location to discuss or share their experiences with others. The discussion can serve to build deeper and richer collective experiences.

We found that the use of the application has afforded students with an effective medium to represent their knowledge alongside with proximal interaction with peers. For example, after taking pictures of the artefacts, some students tagged them in-situ to reflect their prior knowledge about the properties of artefacts or as a form of micro fieldnotes to remind themselves about the functions of the landmarks they have visited or even the interview content with interviewees.

However, in terms of sustaining inquiry, the students did not display much enthusiasm. It is interesting to note that many students actually appropriated the inquiry module for fieldnote taking instead of using it predominantly for inquiry learning. Out of the 28 posts that were uploaded through the inquiry module, 15 were fieldnotes and the remaining 13 posts were questions. A further analysis on the nature of questions revealed that 9 questions were close-ended. This suggests the existence of the "gulf" of intentionality between espoused and actual use of the application. Most of the posted questions were lower order in terms of thinking skills and did little to engender the formation of hypothesis or trigger in-depth discussion. As a corollary of the above discussion, it appears that students show propensity to use ColInq as a knowledge representation tool rather than a knowledge building tool. We suggest that the enculturation of learning habits is important. Students should continue to be exposed to inquiry learning in school and at home for the pertaining learning principles to become internalized. Also, the culture of social learning and peer critiquing has to be fostered.

6. Conclusion

ColInq has the potential to link learning across different spaces, in both synchronous and asynchronous fashion. Students can delve into topics of their interest during or after the trips by filtering the ColInq content through attributes such as location. However, this affordance can be hampered when there is weak GPS signal. Artefacts collected by students thus lost its contextual information. This can affect the student's ability to coalesce a discussion based on geographical interests. To fully realize the potential of ColInq, the application can be enhanced to promulgate inquiry learning by: a) incorporating prompts to help students formulate hypothesis, reflect on the nature of the data they have collected and to draw conclusions by leveraging not only on their own reasoning skills but the collective intelligence of peers; b) providing alternatives to retain the contextual information of the artefacts. We contend that by addressing both the enculturation and system aspects, the spirit of collaborative inquiry learning can be more pronounced.

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