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A mobile App platform for discovering learning profiles and analytics

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Abstract

Attributes of teaching and learning contexts provide rich information about how students participate in learning activities. If snapshots of these attributes can be captured continuously throughout the duration of the learning activities, tracking and analyzing of these learning profiles of individual students will help teachers to identify individual students who need special attention, offer just-in-time guidance to the students in need, and apply suitable pedagogy to suit the immediate needs of the students. This paper describes a platform called *SkyApp* through which teachers can create mobile learning activities and at the same time track and analyze learning profiles of students during and after the delivery of the activities. SkyApp supports capturing, storing and analyzing of fine grained behaviors of students. Through graphical visualization of analyzed results, SkyApp provides insightful information to teachers about the learning characteristics of their students. This study investigates how teachers can make use of the learning characteristics of their students, which were previously not accessible to them, to improve the detailed design of e-learning activities by using SkyApp. The empowerment of teachers by learning analytics has also been evaluated.

Keywords:

e-Learning, mobile learning, learning analytics, learning design, fine grained learners' behaviors.

1. Introduction

Since the introduction of tablet computers educators have been trying to harness its capabilities to support teaching and learning. In addition to the capabilities of multi-touch screen and other hardware features to support e-learning, tablet computers have been supported by the ever-increasing number of apps, which have generated previously unseen possibilities for conducting teaching and learning for primary and secondary students (Murray & Olcese, 2011). With just a few years of experimenting the use of tablet computers in education, recent research has showed that mobile educational apps can bring positive impact on student's engagement (Kucirkova, Messer, Sheehy & Panadero, 2014) and the design and content of mobile apps can affect the quality of students' learning pathways (Falloon, 2013). They can also become useful tools for literacy learning (Hutchison, Beschorner, & Schmidt-Crawford, 2012; Kucirkova, Messer, Sheehy & Flewitt, 2013).

With the infrastructure for mobile learning in place, which typically includes WiFi network, tablet computers and educational mobile apps, primary and secondary schools can adopt a new model of e-learning. This will not only create an opportunity for students to be benefit from the deployment of mobile apps by using tablet computers, but also for teachers to capture the detailed learning records of students in conducting mobile learning activities. It was almost impossible for teachers in the past to provide immediate response based on the learning records that are generated in the class. Teachers can also now explore the possibility of making use of the learning analytics to enhance the outcomes of teaching and learning.

This project aims to develop a mobile app platform that can allow teachers to create e-learning activities and at the same time capture learning records during the activities. This will therefore empower teachers to revise their pedagogies as soon as they received the feedback and learning records in real-time and develop in-depth analysis of learning profiles of students based on the analytics of the learning records collected throughout the period of tracking. This will not only transform pedagogical and assessment practices, but also help students, teachers, school administrators and parents to have a better understanding in the progress of learning of specific individuals. Learning records generated by students are collected in the central data repository of the platform, which allows different stakeholders to assess the performance of individual students continuously. Learning analytics can also be performed to generate insights to review the status of e-learning in the class.

2. Related Works

Researchers have been developing tools to monitor and measure students' learning activity in e-learning environments, especially in the level of higher education. The infrastructure of e-learning allows teachers, school administrators, students and parents to monitor learning records that are generated during the delivery of learning activities, through which the insights of learners' behavior can be obtained by learning analytics (Becker, 2013). Learning analytics (Siemens, 2010) is defined as the use of intelligent data, learner-produced data, and analysis models to discover information and social connections, and to predict and advise on learning. Based on the information collected from different learning activities, learning analytics can also help teachers to identity students with learning difficulties so that timely and strategic interventions can be made (Dawson, 2010).

With the introduction of mobile learning, learning can take place in a variety of situations (Sharples, Taylor, & Vavoula, 2005) and therefore information about the contexts of teaching and learning becomes the additional information that can be included for generating learning analytics. In addition to the traditional information captured by e-learning systems such as historical usage logs, usage patterns and the assessment outcomes of students, context information (Zimmerman et al., 2007) about the time, location, activity, individual learners, and relations between the individual learners with others can be collected by context-aware mobile learning environments. With reference to the framework for context-aware mobile learning that was proposed by Thüs et al. (2012), the platform proposed in this project will capture and process contexts of teaching and learning generated during e-learning activities.

As classified by Wise (2014), learning analytics can be applied by the stakeholders of teaching and learning at macro level and micro level. At the macro level, learning analytics supports the decision making process of administrators that are related to institutional level and beyond. Long and Siemens (2011) refers this type of learning analytics as *Academic Analytics*. Based on the records stored in learning management systems (LMS) and virtual learning environment (VLE), visual graphical tools are built to show activity information of students, which include frequency of using resources, time spent per student in each resource, etc. Notable examples of these tools include, CourseVis (Mazza et al., 2004), Gismo (Mazza et al., 2007), Moodog (Zhang et al., 2007) and Matep (Zorrilla et al., 2008). More recently, tools of learning analytics have been developed to perform analysis of log data in virtual learning environments by Agudo et al. (2013) and in Khan Academy platform by Ruipérez et al. (2014). These analytic tools are often used to determine summative learning data and identify 'at risk' students, however they are pedagogy neutral.

As for supporting teaching and learning at the micro level, tools of learning analytics need to address the challenges of capturing, analyzing and displaying learning data for improving pedagogical practices. For example, LOCO-Analyst (Jovanovic et al., 2008) obtains learning data from online learning environment and presents the feedback data to teachers and the authors of the online courses for evaluation. Based on the context of Social Network Analysis, SNAPP (Dawson et al., 2011) is an analytical tool to provide educators with real-time data to support teaching and learning. These tools of learning analytics are the initial attempts to realize the concepts of the Learning Analytics Cycle (Clow, 2012; Kennedy et al., 2014), which typically consists of four linked steps namely, (1) generating data by learners, (2) producing metrics for analysis, (3) feeding back learners' data and (4) taking interventions. The cycle is derived from the previous theorizations of learning analytics, such as the Conversation Framework by Laurillard (2002) and the works of Kolb (1984) and Schön (1983). To accomplish steps 3 & 4 of the Learning Analytics Cycle, pedagogical actions is necessary to align with learning analytics. As such, learning design (Lockyer et al., 2013) and designing pedagogical intervention (Wise, 2014) are recent research directions through which teachers and learners are empowered to explore pedagogical innovations with learning analytics tools.

However, it is a burden too heavy for teachers to take if they need to carry out the jobs of design, development and delivery of e-learning activities all by themselves. To tackle this challenges, teachers need supports in three areas, namely the facilities to capture learning data, the tools to analyze and present the learning data, and the conceptual framework that can frame the process of data capturing, data analysis and data visualization. This project aims at building a mobile app platform that can be used by teachers as a tool to provide supports in these three areas.

Despite the rapid adoption of educational mobile apps to support classroom teaching in recent years, there are currently very few mobile apps that can keep track of and perform real-time analytics on the fine-grained data about students' inputs and actions created during e-learning activities. The data collected in real-time can then assist teachers in improving their pedagogies in the earliest possible time. In addition to drawing insights from fine grained learners' behaviors, learning records generated by students are collected in the central data repository of the platform, which allows teachers, school administrators, students and parents to monitor the performance of individual students continuously.

3. Conceptual framework to empower teachers for pedagogical innovation

This paper proposes a conceptual framework for teachers to develop e-learning activities based on the learners' behaviors in responding to the different settings of e-learning activities. As shown in Figure 1, this framework includes a mobile app called *SkyApp* that runs on tablet computers such as iPad and a cloud-based service in performing learning analytics based on fine-grained learners' behaviors.

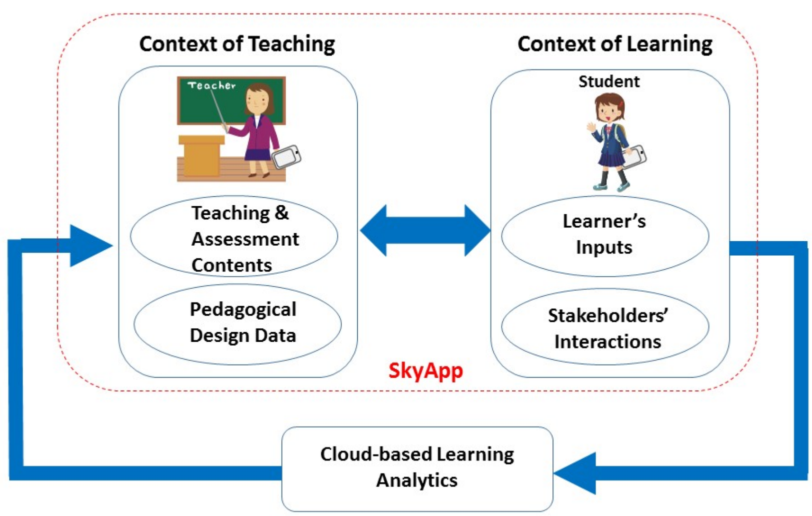


Figure 1. Conceptual Framework for the interaction between context of teaching and context of learning

3.1 Managing interactions between the contexts of teaching and learning

The design of the conceptual framework draws on the Conversation Framework of Laurillard (2002) in which learning processes essentially involves interactive dialogue between teachers and students. Figure 1 also depicts the conceptual components of SkyApp which facilitate the interactions between the context of teaching and context of learning by feeding the data of learner's behaviors from SkyApp to the facilities of learning analytics and then returning the results back to teachers through SkyApp. Learning analytics completes the feedback loop (Kennedy et al., 2014) by helping teachers to visualize the learners' behaviors (context of learning) upon interacting to specific context of teaching which associates with content-specific and pedagogy-specific information.

Based on the functions of managing the context of teaching presented by the mobile app running on tablets, teachers can develop e-learning activities by creating teaching and assessment contents and applying design elements of pedagogical practices such as gamification elements and scaffolding supports to students with different learning behaviors. On the other hand, the context of learning is captured during the learning activities which includes student's inputs and the interactions with other stakeholders of the e-learning activities. SkyApp can then pass the captured information to the cloud-based service for performing learning analytics. It is envisioned that teachers can make use of SkyApp as a design tool for them to enhance the context of teaching and assessment based on a better understanding of the context of learning through learning analytics.

3.1.1 Teaching and assessment contents

Developing teaching and assessment contents for e-learning is one of the most daunting tasks for teachers in adopting e-learning pedagogy. To reduce this burden to teachers, SkyApp allows teachers to develop teaching and assessment contents in developing each e-learning activity simply by file upload or photo-taking based on their existing teaching materials. The uploaded image of the activity can then be split into different parts which are labeled as various questions or sections of the activity. As such, SkyApp can later retrieve individual questions or sections of each activity through searching.

3.1.2 Pedagogical design data

To represent and store the context of teaching and assessment, the pedagogical design data of the e-learning activity is required to be recorded, which includes the basic information of the activity such as date, time and place of carrying out the activity, design elements involved, identifiers of the class and teachers. SkyApp is designed to support teachers to make decisions in adjusting the use of different design elements to achieve better outcomes of learning.

3.1.3 Learner's inputs

SkyApp supports the facilities for students to provide answers or responses to the questions or assessment by typing and handwriting. This enables SkyApp to capture fine-grained learner's inputs such as time spent on each part of the e-learning activity and the details of the handwriting which are essential in supporting data analysis.

3.1.4 Stakeholders' interactions

SkyApp also captures communications between students and other stakeholders. Examples of these communications include exchanging message between parents and teachers pertaining to the details of the e-learning activity and sharing of information and messages among participating students in a class.

3.2 Cloud-based learning analytics

During each e-learning activity, records of learner's activities and interactions with others are collected and forwarded to the cloud-based service of SkyApp. The records are then processed using learning analytics and returned back to SkyApp for visualization. The cloud-based service is able to provide feedback to teachers for assessing the performance of the individual students continuously. Students can also access their own mobile learning records, assessment results and feedbacks from teachers.

3.3 Direction of research

The research of this project tries to address three challenges mentioned by Ferguson (2012), they are using learning analytics to have good learning design and effective pedagogy, exploring other datasets of learning analytics outside that of the VLE or LMS, and putting the focus of learning analytics on the perspectives of learners such as motivation, confidence, enjoyment and satisfaction.

It is envisioned that SkyApp will facilitate enhancement of pedagogical practices in which teachers will understand students' learning behaviors upon each e-learning activity so that the design of pedagogical actions can be revised. This study asks the following research questions:

1. How can the fine grained learners' behaviors be captured during tablet-based e-learning activities?

2. How does the captured learners' behaviors enable teachers to gain insights of students' learning characteristics through learning analytics?

4. Software Design of SkyApp

The current version of SkyApp (v1.25) is a mobile app written in Objective-C to run in iOS tablets. SkyApp communicates with the cloud-based learning analytics to perform analysis with other supporting functions such as database, administration and user authentication. As show in Figure 2, the software design of SkyApp is segregated into four software layers, which are designed to represent the software structure for managing functions and data of four respective functional components of SkyApp as described in the previous section, namely teaching contents, pedagogical design data, learner's inputs and stakeholders' interactions.

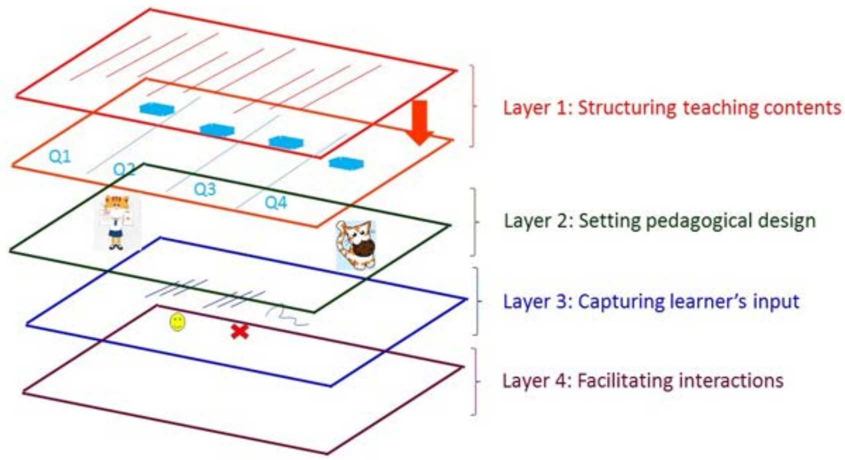


Figure 2. Software layers of SkyApp

4.1 Layer 1: Structuring teaching contents

Layer 1 represents the software structure in developing and handling the contents that are developed by teachers for teaching and assessment. To simplify the process of creating electronic learning artefacts such as teaching materials and assessment exercises, SkyApp allows teachers to upload learning artefacts as digital images.

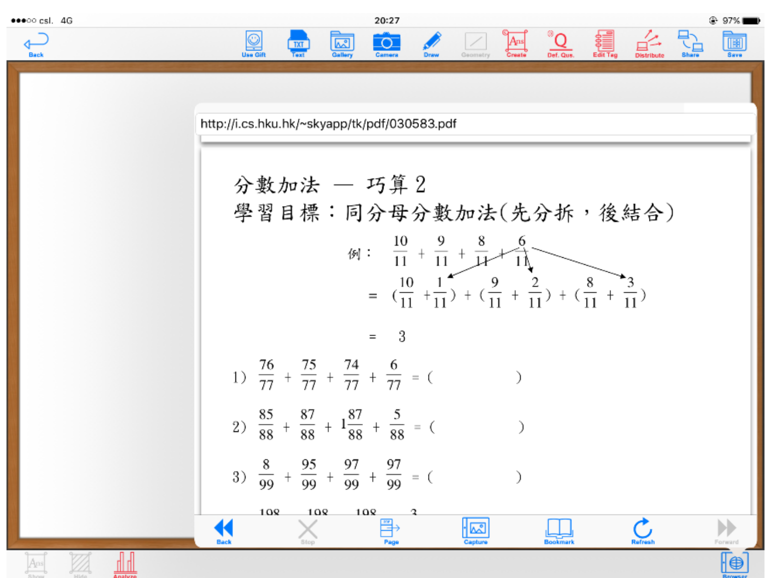


Figure 3. Uploading a worksheet diretly from a designated site

Teachers can simply upload the images through either photo taking or file uploading. This approach will dramatically reduce the workload of teachers in preparing contents of teaching by reusing the existing teaching materials. Figure 3 illustrates a simple way to upload a worksheet directly from a preloaded document stored at a designated site through the in-built broswer of SkyApp.

For the system to store and manage individual parts of the teaching or assessment contents, such as worksheets, SkyApp provides a simple facility to teachers to define the area of each part of the teaching and assessment contents. Figure 4 shows that the uploaded worksheet can be split into multiple questions. These questions can then be individually stored and later be retrieved through SkyApp. To complete the setting of questions, the facility of *Answer Boxes* is used to capture the inputs of learners as shown in Figure 5. Each Answer box supports automatic marking.

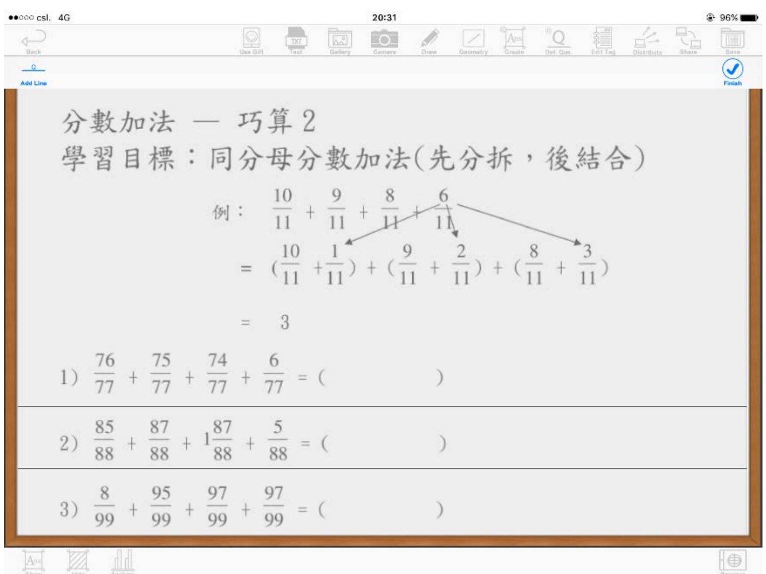


Figure 4. The worksheet is split into multi-part contents by inserting lines on the contents

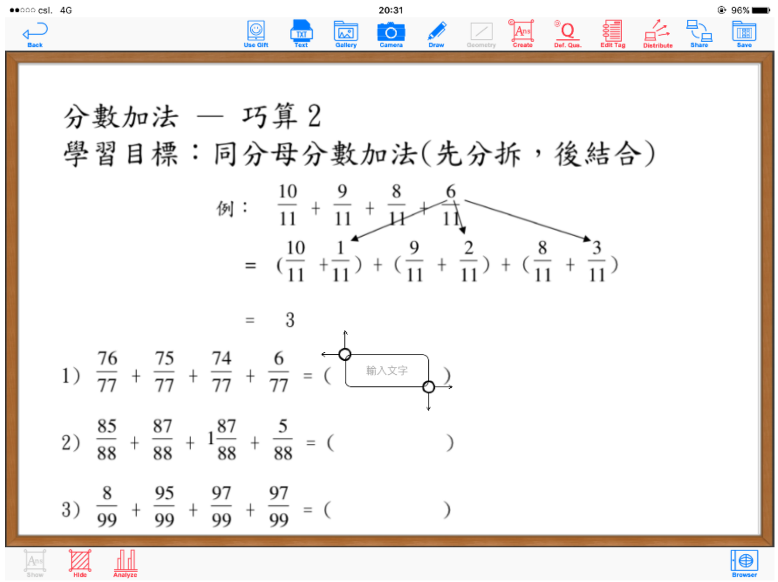


Figure 5. Setting of Answer Boxes to capture learner's inputs

For the communication between SkyApp and the back-end system for cloud-based learning analytics, JSON format as a standardized message format is used to represent the objects created by SkyApp. The attributes of each object include object type, value, dimension and etc as shown in Figure 6.

Figure 6. A typical object of SkyApp in JSON format

Example of an object stored in database is as follow:

[
 {
  "scale" : 1,
  "ansText" : "2",
  "boundsX" : 0,
  "frameY" : 205,
  "string" : "",
  "frameH" : 135,
  "link" : "noCallLink",
  "frameX" : 622.5,

```
  "boundsH" : 135,
  "type" : "dragtextfield",
  "theta" : 0,
  "frameW" : 215,
  "boundsW" : 215,
  "title" : "",
  "boundsY" : 0,
  "ansStatus" : "hideAns"
 }
]
```


4.2 Layer 2: Setting data of pedagogical design

This layer of software design represents the software facilities to manage design elements for supporting pedagogical practices. This layer also helps to define and create the activities of e-learning. Being a key unit in recording data related to e-learning activity, an *e-learning activitiy label* is assigned to represent each newly created activity as shown in Figure 7.

Figure 7. Creating an e-learning activity label for a newly created activity

Different pedagogical design elements can be provided by SkyApp in this layer of software. In version 1.25 of SkyApp, teachers can apply an awarding scheme by giving out cartoon gift icons to student who performed well in an e-learning activity, as shown in Figures 8 & 9.

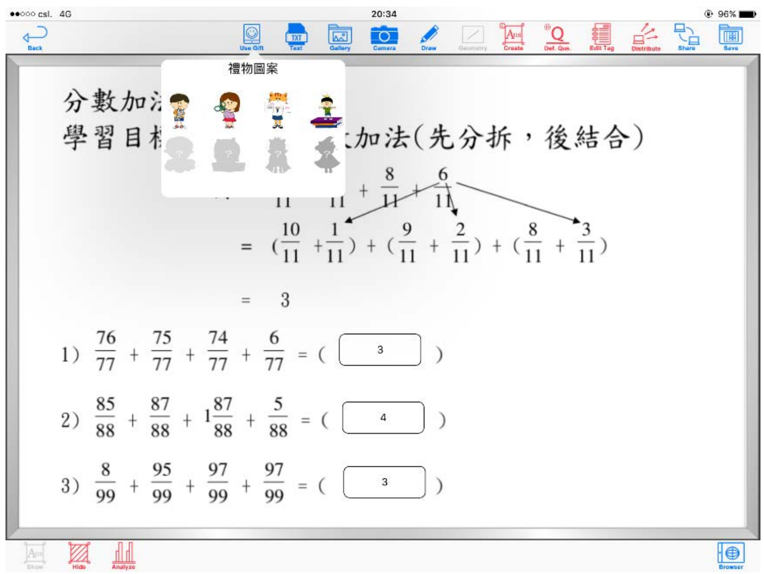


Figure 8. Students are encouraged to collect cartoon gift icons

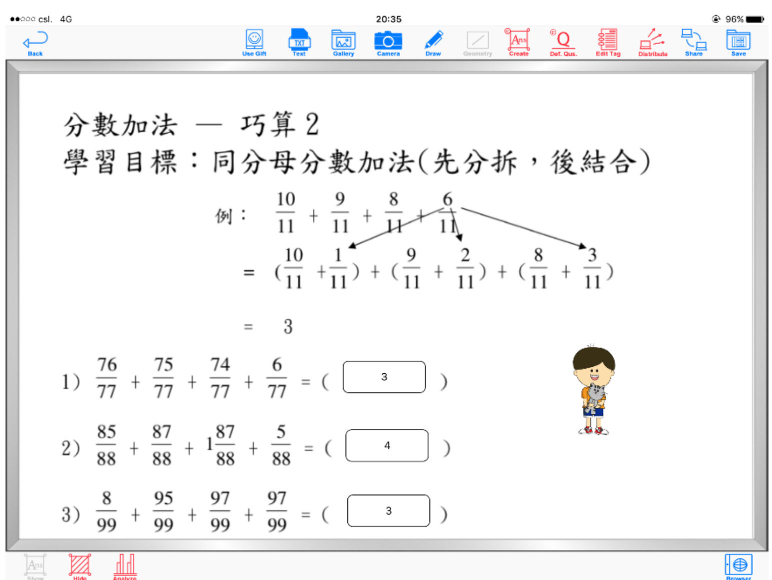


Figure 9. Cartoon gift icons can be posted in SkyApp for decoration

Visualization of students' responses due to different pedagogical designs is also managed by this layer of software. SkyApp supports different views in tracking and examining the responses of students during the e-learning activity, as shown in Figures 10-12. This design element allows teachers to have an overview of most recent status of learning.

Figure 10. Tracking summary of students' responses (Listing view)

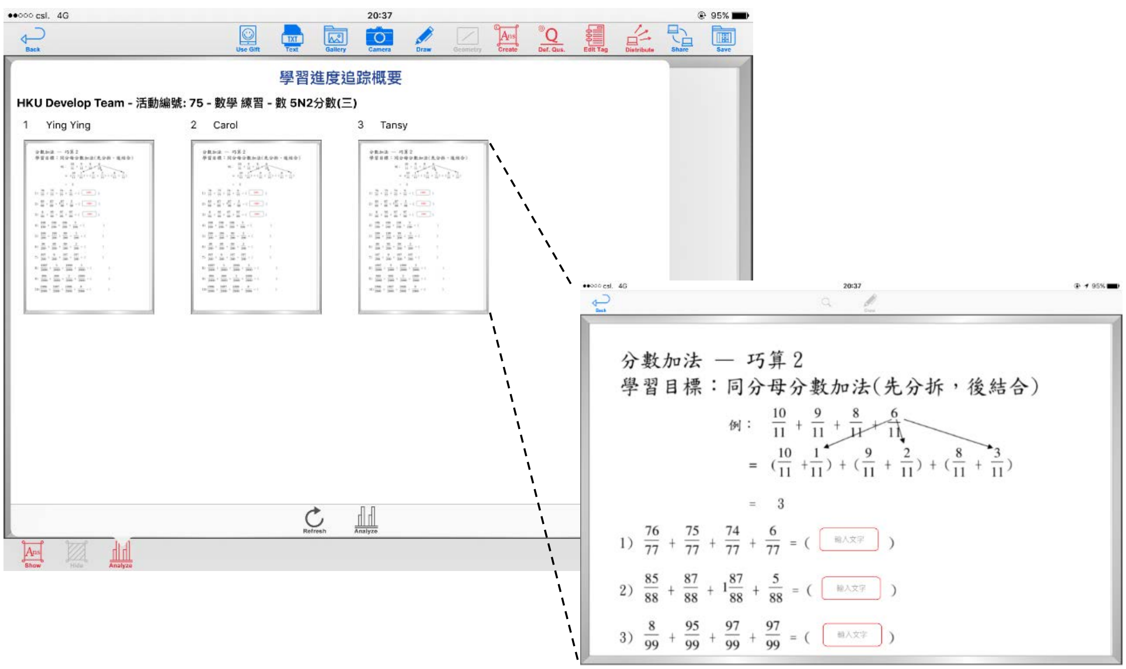


Figure 11. Tracking summary of students' responses

(Thumbnail view and detailed view of each individual student)

4.3 Layer 3: Capturing learner's inputs

This layer of software is designed to capture learner's inputs from different ways, namely entering *Answer Boxes*, handwriting, and adding emojis . For entering answers in the *Answer Boxes*, SkyApp captures the answers entered and can perfrom automatic matching with the modelled answers of the Answer Boxes. SkyApp can also support learners to enter handwriting inputs. By selecting and adding emojis to the SkyApp allow students to express common emtions in participating in this e-learning activity to teachers (Figure 12).

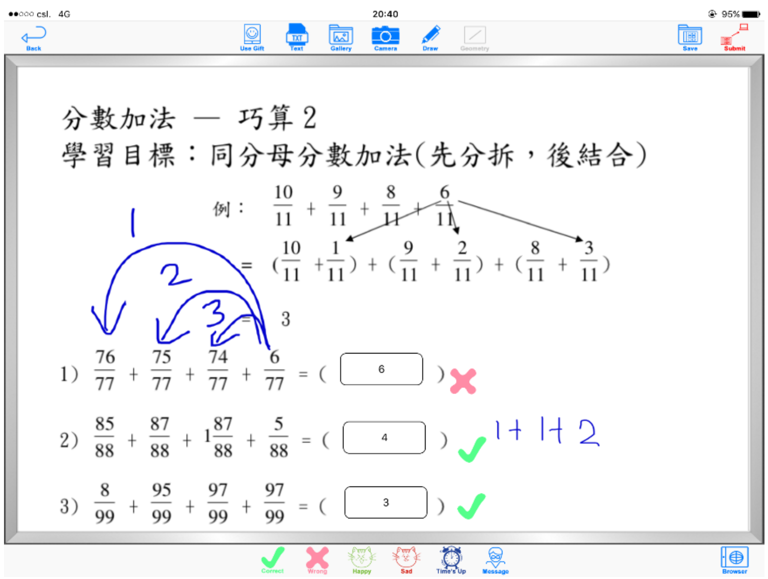


Figure 12. Entering Answer Box , adding emoji and handwriting inputs

The data captured by this layer of software is structured in JSON format before sending to the back-end system for learning analytics. Example of a time-stamped event log that is represented in JSON format regarding student's inputs is shown in Figure 13.

[
{
"device" : "IPad",
"location" : "22.282190761318826588421870 8 114.21756621441986112586164 38 Hong Kong Hong Yue Street Hing Tung",
"submitTime" : "2016-02-20 03:44:04",
"events" : [

{
  "content" : {
    "objectLocationWidth" : "145.500000",
    "objectLocationX" : "586.000000",
    "objectLocationHeight" : "95.500000",
    "objectLocationY" : "238.000000"
  },
  "timestamp" : "2016-02-20 03:44:01",
  "eventType" : "keyboardOnAnsBox",
  "action" : "startTyping"
},
{
  "content" : {

  },
  "timestamp" : "2016-02-20 03:44:01",
  "eventType" : "keyboardOnNoteView",
  "action" : "show"
},
{
  "content" : {
    "typedCharacter" : "3",
    "accept" : "1",
    "objectLocationWidth" : "145.500000",
    "objectLocationX" : "586.000000",
    "objectLocationHeight" : "95.500000",
    "objectLocationY" : "238.000000"
  },
  "timestamp" : "2016-02-20 03:44:02",
  "eventType" : "keyboardOnAnsBox",
  "action" : "type"
},
{
  "content" : {
    "text" : "3",
    "objectLocationWidth" : "145.500000",
    "objectLocationX" : "586.000000",
    "objectLocationHeight" : "95.500000",
    "objectLocationY" : "238.000000"
  },
  "timestamp" : "2016-02-20 03:44:02",
  "eventType" : "keyboardOnAnsBox",
  "action" : "endTyping"
},
{
  "content" : {

  },
  "timestamp" : "2016-02-20 03:44:02",
  "eventType" : "keyboardOnNoteView",
  "action" : "hide"
},
{
  "content" : {

  },
  "timestamp" : "2016-02-20 03:44:04",
  "eventType" : "submitObserver",

```
      "action" : "submit"
    }
  ],
  "count" : "6",
  "activity" : "exercisePre",
  "version" : "1.5",
  "startTime" : "2016-02-20 03:43:53"
 },
 {
  "device" : "IPad",
  "location" : "22.28219076131882658842187O8 114.2175662144198611258616438 Hong Kong Hong Yue Street
Hing Tung",
  "submitTime" : "2016-02-20 03:48:23",
  "events" : [
   {
    "content" : {
     "offsetHeight" : "107"
    },
    "timestamp" : "2016-02-20 03:48:20",
    "eventType" : "drawViewController",
    "action" : "open"
   },
   {
    "content" : {
     "pointX" : "322.000000",
     "pointY" : "420.500000"
    },
    "timestamp" : "2016-02-20 03:48:20",
    "eventType" : "drawView",
    "action" : "touchBegan"
   },
   {
    "content" : {
     "path" : "<UIBezierPath: 0x13781f580; <MoveTo {322, 420.5}>,\n <LineTo {322.5, 440.5}>,\n <LineTo {323.5,
464.5}>,\n <LineTo {327.5, 493.5}>,\n <LineTo {334, 522}>,\n <LineTo {342.5, 535.5}>",
     "pointX" : "342.500000",
     "pointY" : "535.500000",
     "color" : "blue"
    },
    "timestamp" : "2016-02-20 03:48:20",
    "eventType" : "drawView",
    "action" : "touchEnded"
   },
   {
    "content" : {
     "objY" : "415.000000",
     "objHeight" : "249.000000",
     "objWidth" : "299.000000",
     "objX" : "223.000000"
    },
    "timestamp" : "2016-02-20 03:48:22",
    "eventType" : "drawView",
    "action" : "dismissWithStroke"
   },
   {
    "content" : {

    },
```

```
      "timestamp" : "2016-02-20 03:48:23",
      "eventType" : "saveObserver",
      "action" : "save"
    }
  ],
  "count" : "5",
  "activity" : "exercisePre",
  "version" : "1.5",
  "startTime" : "2016-02-20 03:44:08"
 }
]
```


Figure 13: A typical event log of student's inputs

4.4 Layer 4: Facilitating stakeholders' interactions

For the current version of SkyApp, parents or students can communicate with teachers through sharing of text messages, as shown in Figure 14. Another way for SkyApp to facilitate interactions among stakeholders is the function of sharing contents of SkyApp. Figure 15 shows that students can share their notes to another student.

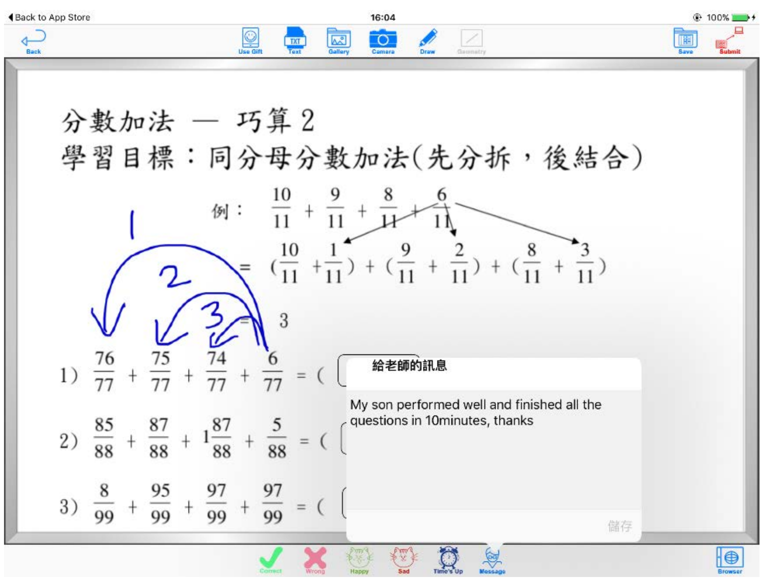


Figure 14. Text comments from parent or student to teacher

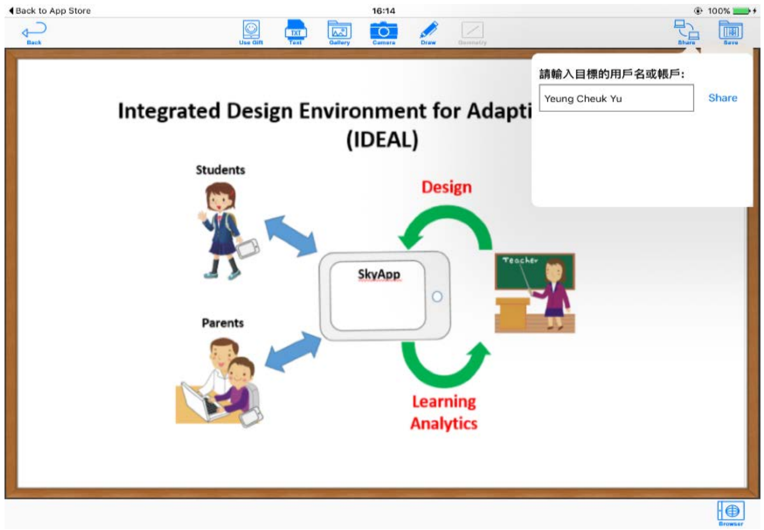


Figure 15. Sharing notes with peers

5. Learning Analytics

5.1 Measuring Metrics of learners' behaviors

SkyApp relates the context of learning and the context of teaching by the e-learning activity label that is created by the teacher who developed the e-learning activity. SkyApp captures the data of learners' behaviors during the activity as part of the context of learning, which can be linked to the corresponding e-learning activity label. The information stored in an activity label include topic and sub-topic of the activity, the type and detailed configurations of the activity.

Instead of just logging the data related to the performance of learners such as the percentage of right answers and the time spent of answering the questions, SkyApp is capable of recording the fine-grained learners' behaviors while learners are participating in e-learning activities, which are basically the typing actions on the virtual keyboard and the actions by fingers or stylus on the touchscreen of the tablet. The data entries recorded through direct measurement by SkyApp are called measuring metrics and are represented in JSON format (Figure 13). SkyApp can capture the measuring metrics of the whole e-learning activity and individual questions of the activity as shown in Figure 16.

5.2 Representing learners' behaviors as learning traits

The measuring metrics are then used to represent learning behaviors which are referred to as learning traits. Based on one or multiple measurement metrics, specific characteristics of learning can be represented. The purpose of defining learning traits is to help teachers to understand meaning of the learners' behaviors. Figure 16 shows a list of learning traits that can be identified by SkyApp.

5.2.1 Learning traits of learning performance

Marks, time spent and thinking time spent on the activity or individual questions are commonly used as performance-based measurement metrics. From the marks, students can be classified by the basic descriptors as very knowledgeable, knowledgeable, unknowledgeable, and very unknowledgeable. From the time spent or thinking time, students can be classified as very fast, fast, slow, very slow. Therefore, performance-based learning traits can be classified based on these three basic descriptors of learning traits, each of which can be represented by a single descriptor. For example, a student with a very good mark and very short time spent (and thinking time spent) in a specific activity is described as "very knowledgeable" and "very fast".

Types of learning trait	**Learning traits**	**Measuring metrics**	**Activity level & question level**	**Remarks**
Learning Performance	Level of knowledge of the related topic	Marks	Activity level	Total marks obtained for each activity
	Speed of learning	Time	Activity level	Total time spent on each activity
	Speed of	Idle Time &	Question level	Different types of time

	learning	Answer Time		spent on each Answer Box
Learning Motivation	Level of engagement	Attempts	Activity level	Maximum number of times a student change the contents in the Answer Box of any question in an activity
	Level of effort committed	Handwriting	Activity level	Total amount of handwriting inputs for solution working
	Level of distraction	Mark & Time & Attempts & Handwriting	Activity level	Deduction from the analysis of multiple measuring metrics
Other characteristics of learning	Level of interaction	Use of emoji, text messages to teachers, and gift icons	Activity level	Interactions with peers, teachers and parents
	Level of sequential working pattern	Answering sequence	Activity level	Patterns of answering questions

Figure 16. Classification of learning traits

5.2.2 Learning traits of learning motivation

Based on other measuring metrics, SkyApp can identify learning traits of students that are related to learning motivation. These learning traits deserve the attention of teachers because teachers can provide early intervention to “at-risk” students. Through learning analytics, teachers can understand the salient features of students’ learning behaviors that are related to learning motivation. Some of these learning traits can be identified by a single measuring metric, for example the measuring metric "the amount of handwriting inputs for solution working" can be used to identify the level of effort committed. Other learning traits such as the level of distraction however requires a few measuring metrics. For example, a student is classified as "distracted" if he/she is unknowledgeable (mark is low), slow (time spent is long, or thinking time is long) and having poor engagement (number of answer submission is low or amount of handwriting inputs is low).

5.2.3 Other characteristics of learning

SkyApp can also capture other learning traits that are not directly related to assessment performance and motivation. These include:

- Level of interaction with teachers and other stakeholders by measuring the inputs of students for communication;
- Specific styles of working by measuring the sequence of answering;
- Specific styles of hand-writing for identifying possibly writing or learning difficulties.

5.3 Profiling of learning traits

Under specific context of teaching, if the occurrence of specific learning trait gains statistical significance, the learning trait can then become the learning profile of the learner. Therefore specific learning profile of individual students can be identified, such as consistent difficulties in learning specific topic. Teachers can be informed to offer specific teaching intervention to assist the student in need. If the learning traits of particular students consistently show sign of learning difficulties, such as highly distracted and very unenthusiastic, teachers should investigate whether the students will require special assistance in learning.

6. Experiments and Results

6.1 Overview of the setting of experiments

To test the effectiveness of the platform, SkyApp is tested by mathematics teachers to deliver e-learning activities in the class for teaching purposes. SkyApp can generally be applied to different subjects, but mathematics is first selected for testing because both the teaching materials and the format of class activities of mathematics are relatively well-structured comparing with other subjects. In addition, there were only preliminary studies (Osmon, 2011; Carr, 2012; Kiger, Herro & Prunty, 2012; Attard, 2013) that have been conducted in investigating the efforts of mobile learning on primary school mathematics.

In addition to demonstrating the use of SkyApp to develop e-learning activities based on the existing teacher materials, the key objective of conducting experiments in the two participating schools is to look for actionable information and to draw insights so that pedagogical actions can be conducted to address the needs of students.

The mathematics teachers of the two participating schools are using SkyApp to explore the effects of using tablets in teaching mathematics. The e-learning activities are carried out as part of the teaching activities to achieve normal curricular goals described in the annual plan of the subject. They are essentially consisted of mathematics questions in the form of worksheet that will be delivered as class exercises, and they are developed for mathematics classes of primary 4 students in two primary schools (hereinafter referred to as School X and School Y). These schools have recently adopted the BYOD policy through which students can bring their own iOS tablets to schools for participating in e-learning activities. To conduct the experiments required, all the students and the teacher in the class are running SkyApp in their tablets which are connected to wireless communication through the WiFi infrastructure available in their schools.

6.2 Analysis of event logs

Records of students' behaviors are captured in the back-end database of SkyApp. To perform analysis of the records captured, an analytical tool is built in Python to extract raw data from the database and convert them into CSV files. Data analytics can then be performed by calling statistical libraries through R programming. Analysis reports and classification results are finally presented graphically in HTML.

The analysis results presented in this paper was formulated based on the data captured by SkyApp for the students of Schools X & Y. In the form of worksheets presented in SkyApp, students are required to finish the questions under a specific topic, such as arithmetic operations of fraction, in each e-learning activity. Through the event logs of SkyApp, the inputs of users can be captured. There are two types of event logs, namely independent and dependent events. An independent event occurs only at one specific instance in time, for example inserting an emoji by a student is recorded as an independent event. A dependent event whereas records information at multiple instances of time, starting by a *start of event* action and following by a series of *in-process* actions until ending by an *end of event* action. During inputting answers in the Answer Boxes (Figure 5) of the questions in a worksheet, inputs are recorded as dependent events. Figure 17 illustrates how *Idle Times* and *Answer Times* of a user can be measured in answering the first two questions of a worksheet.

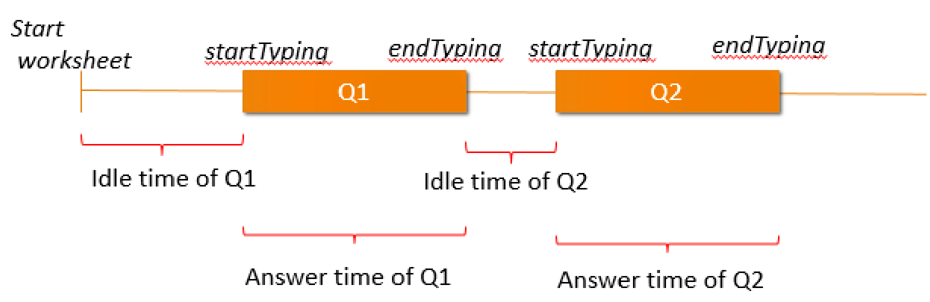


Figure 17. Idle times and Answer times in answering questions Q1 & Q2

Figures 18 and 19 show the idle times and Answer times of Students 472 and 474 in answering the questions in Worksheet 31 which consists of 8 questions of fraction multiplication. 17 Answer Boxes are used in the worksheet and each Answer Box is represented by labels Q1 to Q17. Based on Figures 18 and 19, teachers can gain insights on the following patterns of students' actions:

(i) The time spent by each student in each question;

(ii) The thinking time between answering two questions as indicated by the idle times;

(iii) The times in answering each question as indicated by the answer times;

(iv) The sequence in answering the questions in the worksheet;

(v) The number of attempts in answering each question.

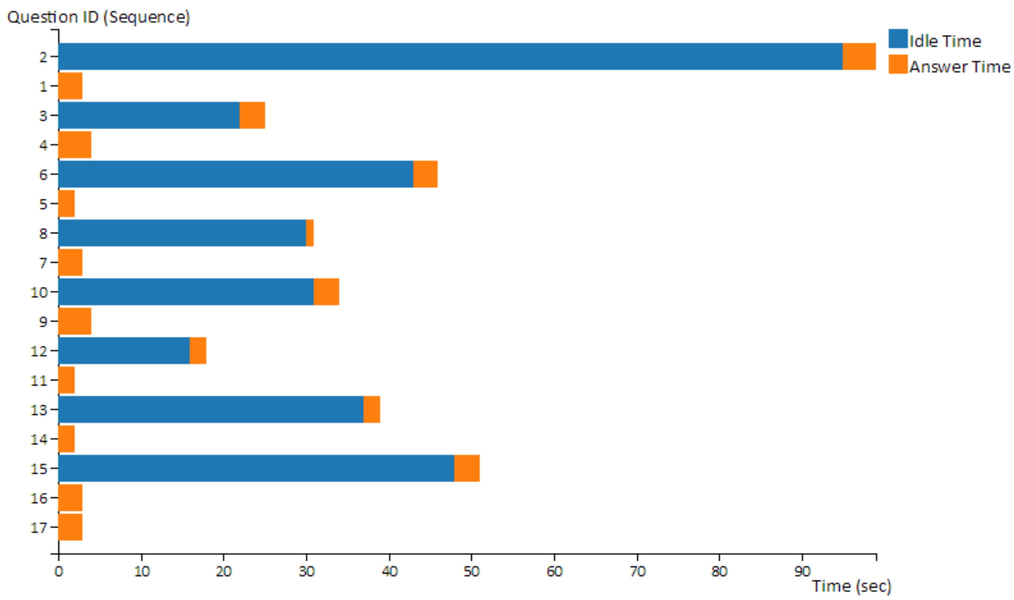


Figure 18. Idle times & Answer times of Student 472 in answering questions of Worksheet 31

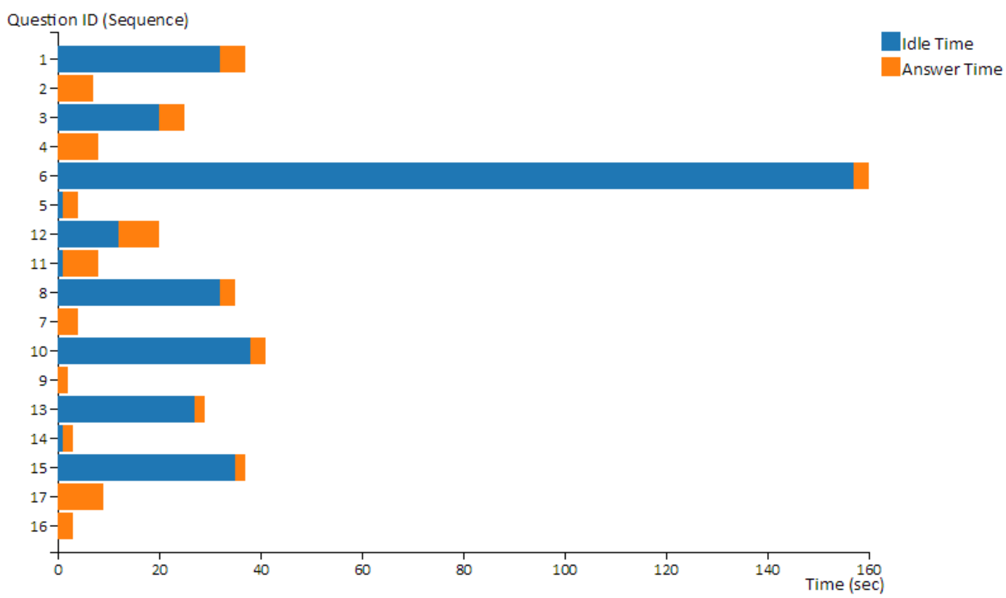


Figure 19. Idle times and Answer times of Student 474 in answering questions of Worksheet 31

The measuring metrics of *Time*, *Attempts* and *Marks* will be used to perform further analysis of learning traits. Based on the information of event logs, the measuring metric of *Time* can then be formulated as the sum of idle times and answer times of all the questions in a worksheet. By examining the maximum number of attempts in answering the same question in a worksheet, the measuring metric of *Attempts* is formulated. As for the measuring metric of *Marks*, it is determined by the sum of marks assigned in each question.

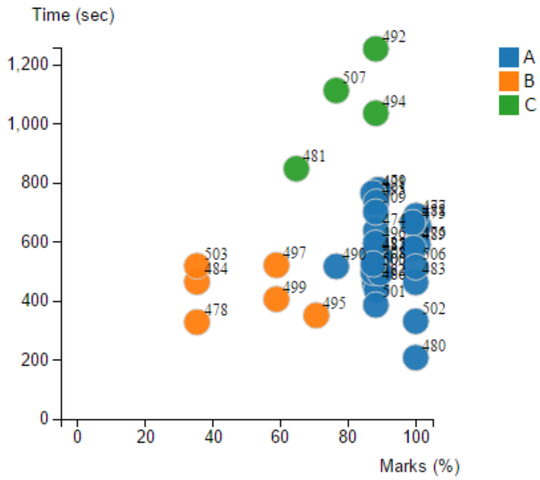
6.3 Classification of learning traits using clustering algorithm

Clustering algorithms can be used to find the data points represented in specific measuring metrics that group together into a set of clusters. Meaningful patterns of learning characteristics can be identified by applying clustering algorithms on one or multiple measuring metrics. As shown in Figure 20, various measuring metrics are used to formulate the different classifications of learning characteristics. Hierarchical clustering algorithm with agglomeration method of *complete* is used for performing clustering of data points captured by SkyApp. Four criteria are used for identifying the best number of clusters, namely Silhouette, KL, CH and C-Index.

Insights out of the analysis **(The learning behavior patterns of the students in the class)**	**Measuring Metrics for clustering algorithms**
Classification by learning performance	(1) Mark (2) Time
Classification by motivation and performance and motivation	(1) Mark (2) Attempts
Classification by learning characteristics and performance	(1) Mark (2) Time (3) Attempts

Figure 20. Measuring Metrics for clustering algorithms

Results of classification based on the e-learning activity of School X:



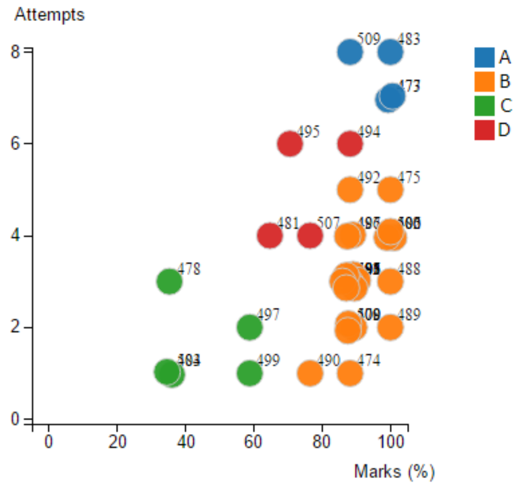


Figure 21.1 Clustering by Time and Marks **Figure21.2 Clustering by Attempts and Marks**

(Classification by Learning Performance) **(Classification by Motivation and Performance)**

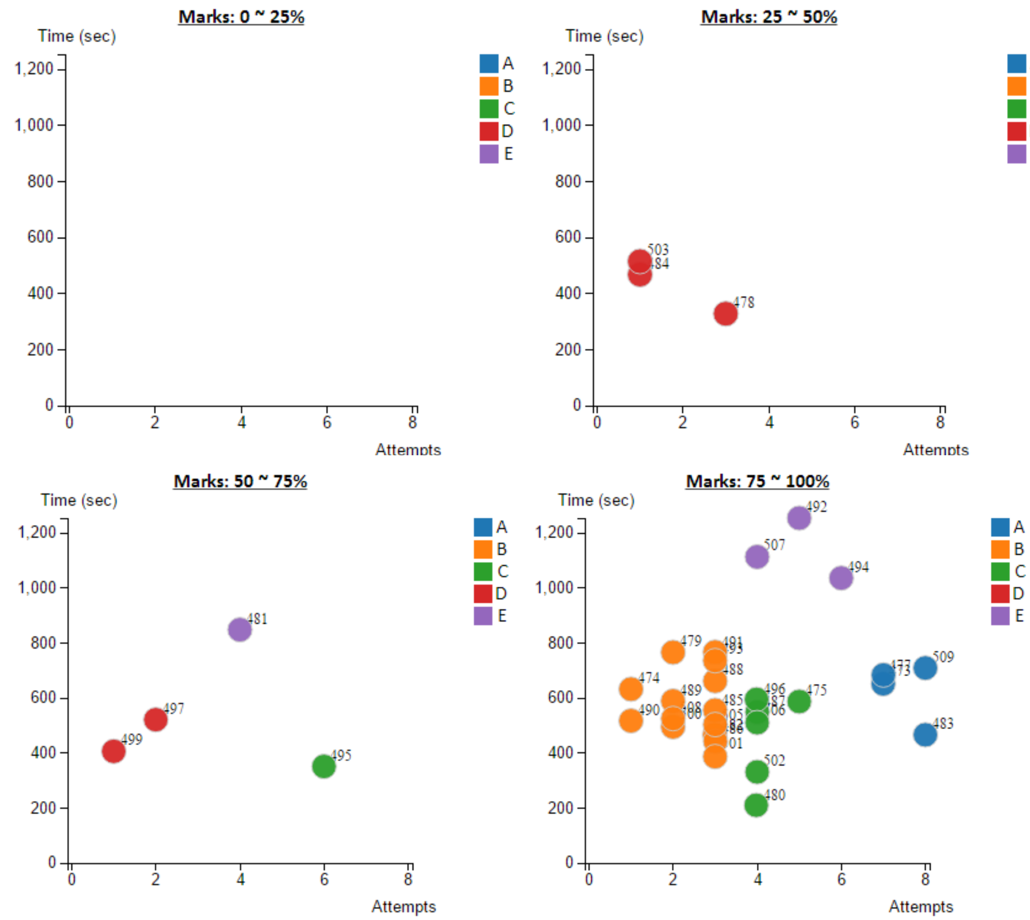
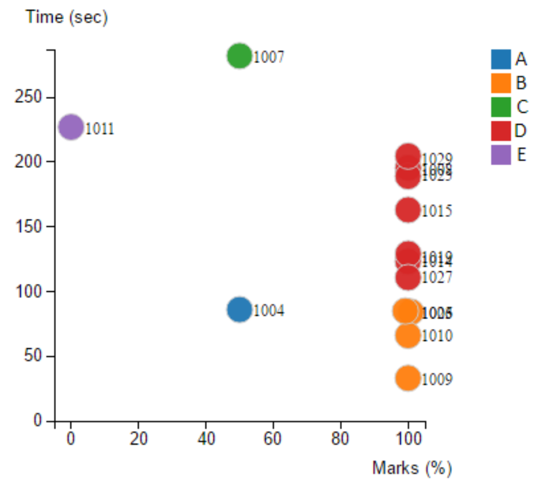


Figure 21.3 Clustering by Attempts and Time in different ranges of Marks

(Classification by Learning characteristics and Performance)

Results of classification based on the e-learning activity of School Y:



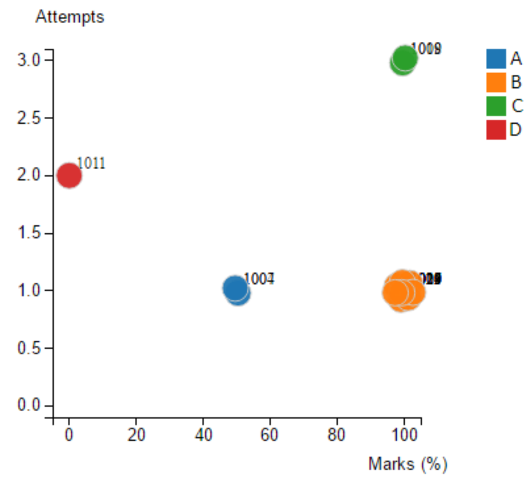


Figure 22.1 Clustering by Time and Marks

(Classification by Learning Performance)

Figure 22.2 Clustering by Attempts and Marks

(Classification by Motivation and Performance)

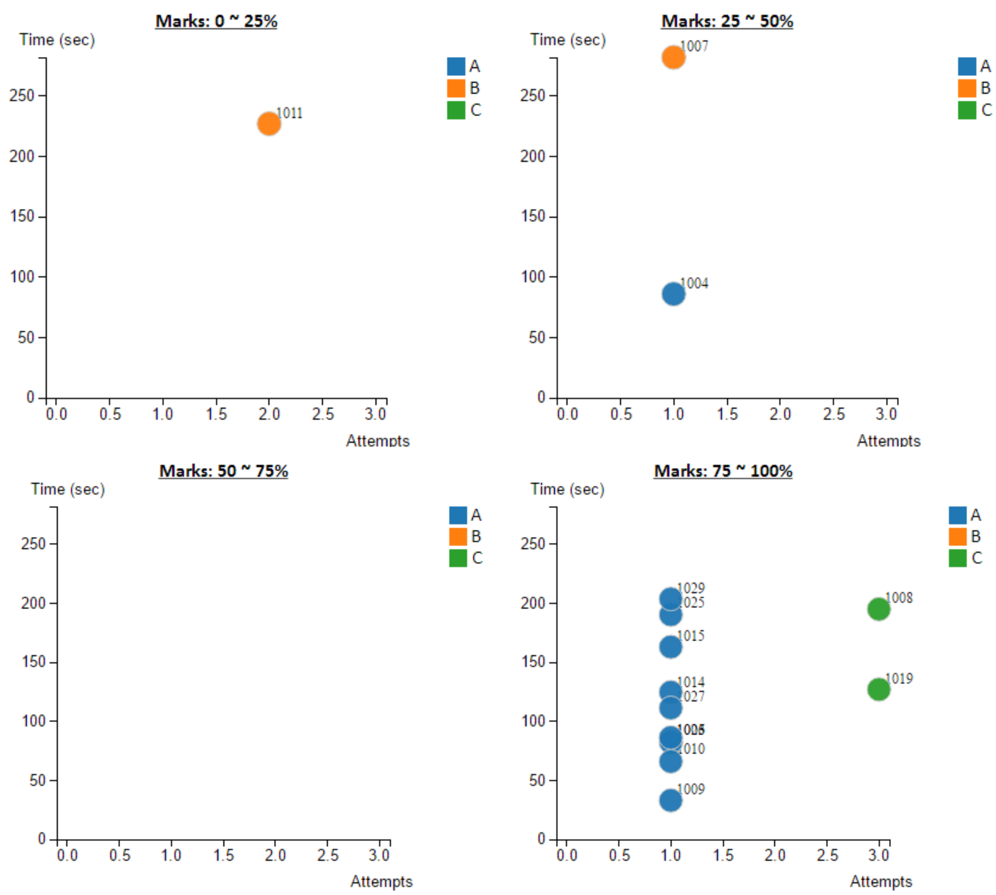


Figure 22.3 Clustering by Attempts and Time in different ranges of Marks

(Classification by Learning characteristics and Performance)

By using the measuring metrics of *Time, Marks* and *Attempts* in an e-learning activity of the two participating schools (School X and School Y), clustering algorithm can be applied. Figures 21.1-21.3 show the results of the students of School X in using SkyApp to complete Worksheet 31 which consists of 8 questions of fraction multiplication. Figure 22.1-22.3 depict the results of the students of School Y to take part in an activity based on Worksheet 50 which consists of 2 questions about testing the knowledge of directions.

Figures 21.1 and 22.1 show the results of clustering based on the measuring metrics “Time” and “Marks” of Schools X and Y on worksheets 31 and 50 respectively. These measuring metrics are normally regarded as performance indicators of learning. To explore the relationship between learning motivation with learning performance, Figures 21.2 and 22.2 depict the results of clustering due to the measuring metrics “Attempts” and “Marks”. By considering “Marks”, “Attempts” and “Time” together, Figures 21.3 and 22.3 present the effects of clustering in a different perspective.

The followings are the insights to teachers due to the observations from Figures 21.1-21.3:

- Most of the students of Cluster D of Figure 21.3 also appear in Cluster B of Figure 21.1 and Cluster C of Figure 21.2. Cluster D can split further into two groups, one includes students 478, 484, & 503 and the other includes Students 497 & 499. The students in the former group scored relatively low marks, tried few number of attempts and took short time in answering the questions. Therefore, these students showed possible signs of relatively low learning motivation and performance;
- Students of Cluster A and Cluster E of Figure 21.3 show efforts in making extra attempts and spending more time in answering the questions;
- Students of Cluster B of Figure 21.3 show relative strength in learning performance among other students in the class.

Insights due to the observations from the Figures 22.1-22.3:

- Most students in the class belong to Cluster A of Figure 22.3 who scored full marks in worksheet 50;
- Students of Cluster B of Figure 22.3 spent relatively longer time in answering but still scored low marks;
- No sign of learning traits that are related to learning motivation can be identified.

The results related to Worksheet 31 carry more information about the learning characteristics of the students than Worksheet 50. Basically Worksheet 31 has more questions and its questions show larger variation in the level of difficulty than that of Worksheet 50. It therefore shows that the contents and design of the worksheet will affect the quality of classification results due to clustering.

7. Open Source Software

Skyapp is distributed as open source software. Currently there are three versions of skyapp:

- Skyapp1 : The version used in this technical report, to be found in:
  https://github.com/leoyeung8310/skyapp1
- Skyapp2 : Variation of skyapp for collaborative programming, to be found in:
  https://github.com/leoyeung8310/skyapp2
- Skyapp3 : Variation of skyapp built by Javascript, to be found in:
  https://github.com/leoyeung8310/skyapp3

8. Conclusion and Future Works

A mobile app called SkyApp is developed to empower teachers to design and develop e-learning activities. SkyApp does not only support the set up of the contents of the activity, but also support learning analytics based on the fine grained learners' behaviors due to students' inputs and responses. Methods in classifying learning traits are proposed. With classification of learners' behaviors, teachers can be informed of students' learning characteristics which will offer insights to make informed decisions in deployment suitable pedagogical practices in addressing specific needs of students.

Tests are conducted to capture learning characteristics of students in using SkyApp to deliver e-learning activities to teach mathematics in 2 participating schools. The tests have demonstrated that the current version of SkyApp is able to:

(1) help teachers to quickly transform their existing paper-based worksheets into e-learning materials. This can reduce the efforts of teachers to create tablet-based e-learning activities by reusing their existing teaching materials;

(2) capture data of fine grained learners' behaviors such as number of attempts, thinking times for asking each question, during participation of e-learning activities;

(3) support off-line processing of learning analytics so that learning performance and learning motivation can be classified.

However, this initial attempt to perform learning analytics on fine grained learners' behaviors of tablet-based primary school mathematics e-learning activities also brought up a number of questions that deserve further investigation:

- **Real-time learning analytics**

  It is important to find out how classification of students' learning characteristics through learning analytics can be visualized so that just-in-time pedagogical actions can be offered by teachers to the students in need. To achieve this, learning analytics need to be implemented in real-time to allow teachers to revise their pedagogies as soon as they receive the in-depth analysis of learning profiles of students based on the learning records collected throughout the period of tracking. The most time demanding part of our analysis is the computation time required by R codes (for running clustering algorithm). Data preparation and graphical processing also demand time during the analysis. It is estimated that there are around 1,000 – 2,000 answer submissions of each worksheet by a class of 30 students through SkyApp. The typical time required is around 6 to 10 seconds to process the data related to each worksheet. Therefore, it is feasible to complete the data analytics required in real-time. In other words, it is affordable for teachers to visualize the results right after the completion of each e-learning activity.

- **Visualization of learning characteristics**

  It is challenging to visualize the data related to learning analytics as the amount of data increases. Clustering algorithm is an effective mean to generate insights to teachers based on the data captured by SkyApp. However, as the number of parameters (measuring metrics) of the clustering algorithm increases, it is difficult to present the key points in the results to teachers who do not normally have training in data science.

- **Classification of learning traits**

  More empirical experiments are required to explore the relationship between the results of clustering and classification of learning traits. For example, the number of attempts in answering the same question may not always directly relates to motivation of students. Evidences are needed to determine the necessary and sufficient conditions for different measuring metrics in classifying specific learning traits.

- **Personalized supports to students**

  It is also important to find out how the classification of students' learning characteristics through learning analytics can be visualized so that just-in-time pedagogical actions can be offered by teachers to the students in need. Through real-time analytics, teachers can revise their pedagogies as soon as they receive the in-depth analysis of learning profiles of students. Teachers can also introduce specific design elements such as gamification elements to address the special needs of students, and supports of scaffolding according to the pace and style of learning of individual students.

In addition to the application of learning analytics in primary and secondary school education, the research on the current version of SkyApp can also be extended to different forms and levels of training and education.

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