Effective tablet dashboard interface for innovative pipelined multi-teacher lab practicing management

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Abstract— **Lab practicing as a common form of experiential learning is important in engineering education. With the increase of number of students, it becomes a challenge to achieve an efficient organization of lab practicing activities. To address observed drawbacks of standard approaches, in this paper, a pipelined scheduling of timeslots is described and applied in multi-teacher classroom. Innovations in lab practicing policy require new software tools that support new policies and make them possible and effective. Supporting tool for collaborative lab practicing management was implemented on Android tablets and Google Drive Spreadsheet cloud platform. The tool was designed with principles of dashboard interfaces design to be efficient for use in a dynamic lab environment. Effective design solutions within limitations of spreadsheet platform were presented. The tool is used and monitored for two semesters. Errors detection and correction, as the main potential risk, were analyzed and it is shown that users successfully solved with tablet interface all but one type of error, which was corrected from web interface. Main findings confirmed that beside a number of potential risks and sources of errors, it is possible to build a dependent application on spreadsheet platform for use in complex environment of collaborative lab practicing management.**

I. Introduction

Lab practicing, as a form of experiential learning in blended or in traditional, non-distant learning environments, is widely accepted in many fields. In engineering, lab practicing is of great importance to help students' adoption of new concepts and to be able to combine theory with practice [1], [2]. Having an opportunity to experiment in presence of a teacher is especially useful for students in introductory courses, where basic skills should be developed in a proper manner.

Lab practicing takes different places in different courses. Designing lab practicing within a course, course authors decide about number and scope of exercises, timeslot duration, presence and policies of reporting and assessment, and combination of those decisions creates variety of lab practicing sets.

Collecting the students' results, answers and solutions as part of lab practicing activities can be performed in different ways. Depending on the nature of lab practicing, final solutions can take various forms. When written students' answers are simpler, the process of grading students can be done automatically, using some digital assessment and grade annotating tool. When students' answers or solutions are more complex, the process of checking the correctness usually involves domain specific solutions [3].

With permanent demands to increase number of students in higher education, efficient organization of teaching process, and lab practicing as a part of the process, becomes more important.

A. *Traditional lab practicing organization*

Essence of lab exercises execution methodology in most cases can be described with the same simple scenario. Typically, students are divided into groups of 10 to 20 and timeslots are scheduled for groups sequentially. Assignments are administered in advance or on site at the beginning of the timeslot. The teacher responsibilities are to manage administrative tasks, to provide instructions and assistance on equipment, tools and the process, and to help students in achieving correct solutions. Lab practices are by instructional design of the course usually graded, either during the timeslot or deferred. In traditional, or human-to human approach [4] the teacher is responsible to check student's results and solution and grade the student. In this standard approach, lab practicing classes are managed by one teacher where paper and pen are often used to write down students' grades, to write comments and additional data. The traditional lab practicing involving immediate human-to-human assessment by the teacher should be planned carefully as its efficiency depends on many factors: the number of timeslots and students, the size of the students groups, the complexity and difficulty of lab exercises, the preparedness of students etc.

For the sake of comparison, described approach will be identified as *Sequential, Single Teacher Lab Practicing Policy* (S-ST-LPP). The main problems affecting lab practicing efficiency in this approach are:

Inefficient engagement of lab resources. Lab equipment, computers, or another apparatus are not fully utilized during sequence of lab exercises timeslots. Student absence leads to unutilized laboratory workplace for entire timeslot. Students that finish earlier or those that are insufficiently prepared to continue working, leave the lab, thus making part of laboratory equipment not used until the arrival of following students groups.

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Imbalanced needs for teacher engagement during a timeslot. Due to the nature of lab practicing training and assessment policies, the teacher was usually mostly unallocated at the beginning of the lab class and gets overallocated towards the end of a class, often resulting delay in start of the next timeslot, and/or students' feel of unfair marking. For the same reason, students often have to wait longer for teacher attention. Severity of this problem is proportional to number of students in a lab.

Unfair treatment of students. Source of feeling of unfairness is that scheduled timeslot may be too short for some students to fully comprehend all aspects of given problem and to manage to reach complete solution. S-ST-LPP is not suitable to deal with this issue, since leaving students to work longer would prevent some students from the next timeslot to start, thus resulting in new unfairness.

II. Pipelined lab practicing organization - varying the invariable

Broad range of real life systems can be represented with a set of elements that provide a service (*service facilities*), and the number of input elements (*customers*) that use the service. The problems of analysis and modeling of such systems are established and considered by queuing theory [5]. Queuing theory considers different system characteristics or objectives such as the arrival rate, the service rate, the number of service facilities, employed queue disciplines, mean waiting times etc. In respect to queuing theory, the classroom could be considered as a service facility while the students could be treated as customers. Students arrival rate describes how often students enter the classroom and service rate determines the speed of lab completion. In order to provide more efficient lab practicing activities, basic knowledge from queuing theory can be applied to the lab practicing activities organization.

To improve lab practicing efficiency with the new approach, the student arrival rate and the number of teachers are changed. Instead of scheduling common arrival times for all seats in a laboratory, arrival times are spread in a pipeline manner. With the goal of obtaining optimal lab resources utilization, we expected to find a suitable correlation between the students arrival rate and lab resources availability. To achieve this it was necessary to reference some earlier obtained data to get an average rate of students' lab completion and lab resources availability. Approximated completion rate in earlier lab practicing classes can be used to fine tune student arrival times. Having in mind the characteristics of students' activities in the classroom, the increase in the number of teachers should bring better service rate in the periods of burst activities. With these two modifications, we refer to this new approach as *Pipelined, Multi-Teacher Lab Practicing Policy* (P-MT-LPP).

S-ST-LPP and P-MT-LPP are illustrated in Figure 1. Bolded numbers at the beginning of timeslots TS1-4, represent appointed number of students in the given time slot and subsequent not bolded numbers are numbers of students that remain in the lab after defined time intervals. In S-ST-LLP (Figure 1.a.), lab workplaces occupancy decreases during a timeslot, leaving equipment unused until beginning of the next timeslot. Pipelined schedule approach is shown in Figure 1.b. In this approach, after the time interval within timeslot, when some of students already left the lab, additional students are scheduled and introduced to the lab. In that way, available working places inside the lab are rescheduled as fast as they are expected to be freed. Bar charts in Figure 1 represent the percentage of occupied lab seats in time. It can be seen that P-MT-LPP maintains high lab resource occupancy, except at the end of the day, when there is no new students. Furthermore, students start working in different moments, implying that demands for teacher attention will be also spread in time more evenly.

With the introduction of pipeline approach, it becomes possible to have students that begin and those that completed exercise in the same classroom. This sole fact brings difficulties in managing lab practicing activities using paper and pen, as it becomes very difficult to track student progress, and also to synchronize activities between many teachers present simultaneously in a lab.

The solution to make P-MT-LPP possible is found in designing and implementing of collaborative application for managing lab practicing.

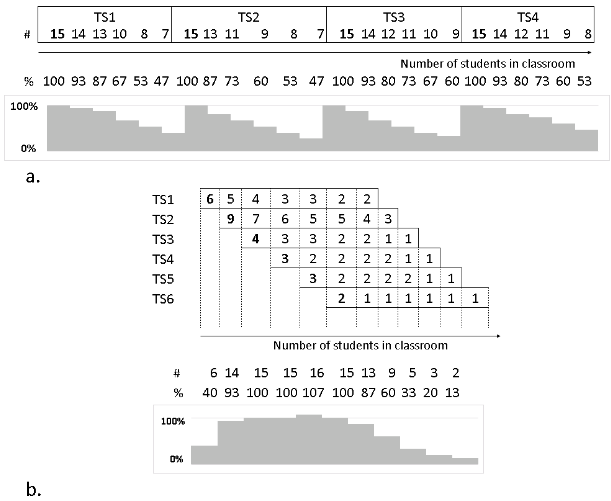

Figure 1. Scheduling of student arrivals to lab practicing classes, a. sequential, b. pipelined approach

III. Design requirements

To deal with the challenges of the newly introduced P-MT-LPP approach and to overcome limitations of paper and pen, it was necessary to introduce software tool that supports work in multi teacher environment.

The design of the management application and the platform choice has to be carefully planned to ensure that several critical aspects are satisfied: **Usability** - the application on the chosen device screen has to provide information and to allow editing data for currently active students with minimum of interaction, e.g. scrolling, opening and closing of dialogs etc, interface should provide means for searching and sorting of data. **Performance** has to be acceptable because data are accessed and modified frequently, in a dynamic environment. **Robustness** – the teacher needs to be able to easily correct errors in data. **Battery life** – working with large groups of students and mobility inside the lab requires that the portable device needs to provide long enough battery life. **Network connection and synchronous work** – multiple teachers collaborate in a lab, demanding that data have to be synchronized between instances of the interface.

Teachers were involved in all aspects of the design of the user interface as well as in identification of required data. Data are classified depending on frequency of changes during the course of lab practicing classes. Constant data are determined once, in the lab planning. Example of constant data is student personal data, including name, ID, and scheduled arrival and finish times. There are data that change between classes, e.g. student profile – data related to previous student's performance during lab practicing cycle or in other activities, thus easing assessment. Another example of such data are lab exercise #. ID of the workplace, as well as grades and comments are data that are changed by the teacher at least once per class. Student grades are inserted only once, while comments are modified several times during the class. Data also include instrumentation data that are collected by the application and can be used for performance analysis.

Working with teachers, several aspects of additional useful functions emerged. The time students spend waiting for teachers attention may not be taken on account of the student and timer needs to be stopped during those periods. The interface should provide assistance to teachers prioritizing students that need to be visited, when multiple students ask for assistance or identifying students that should be visited even if they do not ask. Interface has to be flexible and with only advisory role, all decisions must be left to teachers. Student - teacher communication is structured in advance with checkpoints defined during the class. The application interface needs to provide multiple communication points with possibility to insert and edit separate comments and grades. By implementing this feature, all students obtain an equal attention of the teacher, and early checkpoints help the teacher to identify students with problems in early phases of the class.

IV. Design and implementation

A. Spreadsheet platform for dashboard interfaces

Designing the application, principles of dashboard interfaces design [6] were adopted, bringing together relevant information for teacher to perceive student profile, progress history and current status. Choosing dashboard approach makes the interface efficient during dynamic interactions in lab practicing management. Relevant information need to be arranged to fit mostly on a single screen and to be monitored clearly.

Spreadsheets are considered not suitable for building dependable applications, due to multiple risk factors, design limitations, performance issues, etc. [7]. Despite all evident flaws, spreadsheets became practically ubiquitous in specific fields such as financial reporting [8], and established themselves as widely-used platform for prototyping [9], development of applications by end-users [10], [11], and for rapid and low-cost development of applications for small user base. Having in mind those common uses, and being fully aware of specific design principles of spreadsheet applications, spreadsheet platform was chosen for designing the system for lab practices administration and marking. Although spreadsheet applications design requires specific design principles identified and documented in literature [12], [13], there are many unique details that have to be addressed in particular implementation. The final design must be highly driven by capabilities and features of the chosen platform.

B. Implementation

Dashboard interface of the lab practicing management application was implemented using Google Drive Sheets platform. Application was tested and used on Android tablets Asus Transformer TF-700 with 10.1“ 1920x1200 pixel display, running Google Drive Android application, version 1.1.592.10. and latter updates. Although notebook computers were also considered for purpose of managing students in a lab, tablets were chosen as they fit better in dynamic environment of lab practicing and in mobility level required for teachers.

Google Drive Sheets is a free cloud platform, supports essential programming elements (formulas, conditional formatting, scripting), as well as simultaneous collaboration and editing at the document cell level, using variant of WEBDAV standard protocol. Supported features qualified the platform for development of management application. Due to cloud nature of the platform, an active internet connection over Wi-Fi has to be available.

According to the previous defined data model and runtime requirements, spreadsheet document was extended with conditional formatting statements to control visual aspects of dynamic data presentation, formulas for simpler data manipulation, JavaScript code for complex data manipulation and control. In total, for implementation of the interface for one sheet, 332 lines of JavaScript code, 11 different formulas, two different conditional formatting statements, and one protected region was used. One sheet was created for each class/week in lab practicing cycle, with necessary modifications in formula, and one additional hidden sheet for storing of program variables.

Design of visual elements was driven by specific attributes of spreadsheet interface, but also with limitations of the platform, i.e. current feature set implemented in Android Google Drive application [14]. For example, sparklines feature is implemented in Drive application for web, but not supported in Android application. For that reason, marks history was implemented as numeric string, rather than as a sparkline. Column filtering and searching is not implemented in Android Drive application and sorting is of very limited usability. Alternative solutions for implementation of numerous tasks (i.e. searching for active students, searching for student asking for marking) needed to be developed.

The design, the data model and the final visual appearance of the application were adjusted to specific needs of particular course. Implementation was tailored for lab practicing cycle where two checkpoints, i.e. subtasks, named A and B are required during each class. Only passing mark on subtask A qualifies the student to start subtask B. Student is not allowed to work on the next lab exercise until passes previous one. Official timeslot for a student is 90 minutes of which 22 minutes for subtask A. Periods when the student is waiting for a teacher are not taken into account.

The application interface for one lab practicing class is shown in Figure 2. Interface is divided in sections by columns. Columns displaying student general data (A-F), student profile (G-H) and remaining time for a subtask (J) are generated and read-only. Columns K-L and N-Q are for data entry: Lab# (that is generated but can be overridden), PC#, comments and marks for each subtask. There are 12 additional columns on the interface for quantitative instrumentation, remaining time calculation, and for status variables. These data are automatically generated, but also accessible to the user by panning the interface.

Students are sorted by scheduled time and teachers call them in that order whenever there is available seat. During the lab exercise teachers visit students on demand or after the deadline, and note comments and marks. When student receives final grade, corresponding datasheet row is marked with smaller font. Teachers can scroll or zoom through student list, but typically all active students can be seen on a single screen.

Dashboard interface requirements in one hand, and platform's limited set of features on other, posed multiple challenges designing and implementing required functionalities. Some of requirements and implementation solutions were listed below.

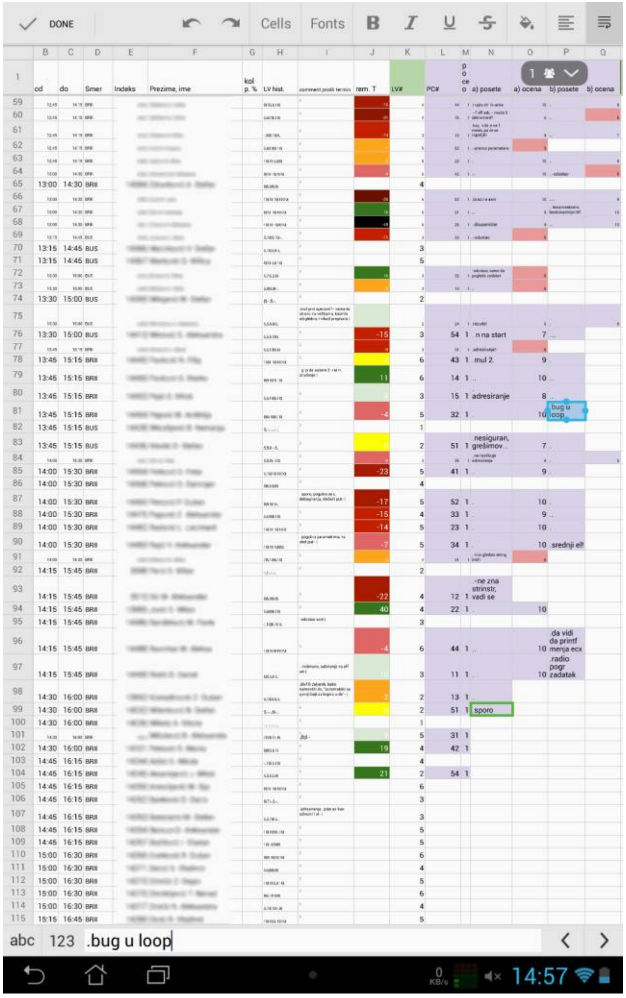

Figure 2. Application interface on the tablet

Attendance and marks history (Figure 2, column H) was generated as a string. Previous classes/weeks were represented with a numeric mark, or with "-" sign in case of absence. Passed mark is followed by "|" character, failed mark with comma. According to this syntax, the column H from Figure 3. shows that the first student was absent for first 3 weeks, then passed first lab practice from second attempt, the second student passed 3 labs in 5 attempts, etc. During development, several different solutions for compact marks history display were presented to users, including line and bar sparklines. Users have chosen string with described syntax as the most descriptive, and easy to understand. For this reason, it turns out that absence of sparkline support in the platform was not limiting for usability of the application.

History of significant notes. To mark a note as significant teacher enters "-" sign within the note. Significant notes are displayed in note history field next week. Notes for subtasks A and B are separated with the "|" character. On Figure 3, student in the second row had significant comment for subtask B only, while third student had comment for subtask A, while comment for the second student in subtask B was not recorded or not marked as significant, thus it is not shown.

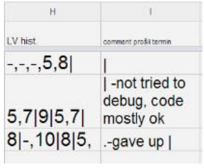

Figure 3. Design solutions for attendance and marks history string and significant notes from previous class

Remaining time. Cells with remaining time (Column J on Figure 2) are color coded, showing how urgent the student should be visited. Cells with positive remaining times are colored in green, while cells for students that passed the deadline are colored in gradients of red.

Visualization of student progress. Students who complete exercise are marked with smaller font. Progress of students through checkpoints is visualized by simulated progress bar – background of non-empty cells in columns for comments and marks is colored (Figure 2, columns L-Q), and fail grade for a subtask is marked with red color. In this way, teacher can visually scan for active students, to determine their progress stage and choose most critical student to visit.

Searching for student record by PC#. This design requirement was left unimplemented. Teacher must visually scan for PC# among active unfinished students. Active unfinished students can be distinguished from finished or absent ones by looking at the number from PC# column written with normal font size.

V. EXPERIMENT

A. Sample

The new approach in lab practicing organization was employed within undergraduate course Computer systems, introductory computer architecture and assembly language programming course held at the Faculty of Electronic Engineering, University of Niš, Serbia, during last two school years. Two teachers managed lab practicing in a lab with 23 seats. In second school year, one group of 26 students was used as control group. The control group is scheduled in separate time slot, not overlapping with others, single teacher managed control group. The lab location, specific tasks and assignments, software tools and topics were unchanged between control and test groups. The statistics of the application is shown on Table I. Duration of work in one week was calculated as average for all observed classes in a cycle, while total usage time was calculated as a sum of durations for all classes, for test groups multiplied by 2, since two teachers were using the application simultaneously.

TABLE I.
SAMPLE SIZE AND MONITORING STATISTICS

	Cycle 1	Cycle 2	Control group
Period	Dec 2012 -Jan 2013	Nov 2013 -Jan 2014	Nov 2013 - Jan 2014
Number of students (N)	139	153	26
Classes/weeks	4	7	7
Timeslots per week	19	24	1
Total duration of labs in one week – average (std dev)	6h53min (26min)	8h2min (23min)	1h44min (8min)
Total application usage time	55h	112h	12h

B. Method

To measure performance of the lab practicing policy and performance of the management application, three data collecting mechanisms were implemented: (1) instrumentation implemented within the management application, (2) special monitoring tool installed on tablet devices, and (3) written structured reports by teachers.

The special monitoring tool was implemented as Android application and installed on user devices. The tool logged teacher's activity and inactivity periods by logging periods of time device screen is turned on and off. Teachers were instructed to keep device screen on while are communicating with students, and to turn the screen off when they are idle. Monitoring tool also provided simple interface for teacher to log occurrence of some of common potential problems. The list of possible problem types was built into the tool and users were instructed to log each occurrence of a problem, and problem type. With the built in Help functions, the tool also reminds a user on solution method for detected problem. Teachers were also asked to write short report after each class and to list observations on system performance, and uncommon problems occurrence. Logs from monitoring tool were collected and analyzed together with user reports during Cycle 2 and control group.

Using collected data, a detailed analysis of different aspects of applied policy performances can be performed, and multiple measures can be established. We will define and analyze only two metrics, while more detailed analysis is beyond the scope of this paper. *Teacher engagement rate* is defined as percentage of time during lab practicing a teacher is engaged managing, helping or accessing students, demonstrating also fraction of time teachers are idle. *Equipment engagement rate* is defined as percentage of lab resources used during lab practicing, demonstrating efficiency of resource usage.

To analyze quality of the management application, logs from monitoring tool were analyzed to find occurrence ratio of presumed common errors and problems in monitoring tool usage. User reports were used to complement problem list and to learn more about user experience using monitoring tool.

C. Results

By analyzing log files exported from monitoring tool and instrumentation data collected with the management application, lab resources and teachers time engagement during two cycles of lab classes were measured. In control group the teacher was active during 81% (std. dev. 8.8%) of total time. In test groups, where two teachers were present, one of the teachers was active during 89% (std. dev. 1.4%) and the second during 75% (std. dev. 14.8%) of the total duration time.

Regarding equipment engagement rate, i.e. PC usage rate, for control group average is 52% (std. dev. 39.29%), while for test group average is 85% (std. dev. 13.0%). Values are obtained by dividing total duration of PC activity with the total duration of all classes.

Detected problems with management application, their occurrences and actions that solved problems are shown on Table II. First 5 problems were anticipated as common and teachers recorded their occurrences with the monitoring tool. Three more problem types were recorded in the written reports. In total, teachers reported 177 problem occurrences. For 124 hours of monitored application usage, one problem arises in average at each 42.03 minutes. Only 5.65% of problem occurrence was not possible to be solved using tablet interface. The most frequently reported was the problem finding particular student record by visual scan (41.8%). Users stated in written reports that this problem emerges only later during the lab classes, and that they almost do not have that problem in first half of the day. Teachers reported that they did not have problems with understanding data on the interface or remembering syntax for marking and viewing significant notes and reading lab history. Loosing network connection occurred only once on a single device and connection was restored within less than a minute. Most severe reported problem appeared after Google Drive application update to version 1.2.484.18, on Dec. 18 2013). Performance was degraded significantly due to forced document reloading on each change by other user. Entire day of lab practice was affected. Until next week Google support was contacted but they were unable to solve the issue. In order to mitigate the issue and restore previous user experience level, additional work was invested to find workaround and to make necessary adjustments.

VI. DISCUSSION

Changing lab practicing policy aimed to improve efficiency of lab equipment usage, teacher time usage and overall lab practicing efficiency. Proposed pipeline scheduling and multiple simultaneously managing teachers, while very complex to perform, if supported with effective software tool, can be possible to manage, and leads to better efficiency.

From the teacher perspective, the new approach to lab practicing management is much more intensive and harder to perform. This is reasonable with pipeline approach, as laboratory resources, equipment and teacher's time are intended to be used most of the time. Comparing the tablet device dashboard interface with earlier paper based annotation, the application interface comprises of all necessary data elements to support the teacher activities during lab practicing classes and provides additional features not possible to implement otherwise. With adaptation of simultaneous editing features it became possible for many teachers to assess same students and to have an insight in all of notes made by any other teacher.

Benefits of the spreadsheet platform include flexibility, allowing invention and adding of new functionalities in the application 'on-the-fly'. For example, teachers at the end of the semester marked students that were given certification of lab practicing completion. For marking, they used background color for name cell.

TABLE II.
USAGE PROBLEMS, FREQUENCY AND SOLUTION METHODS

Problem type	Occurrences			Solution method
	N	per h	Solved*	
Wrong PC#	48	0.39	48	Entry edit
Comment for wrong student	21	0.17	21	Cut/paste
Presence for wrong student	9	0.07	9	Delete data in columns M, R, S
Mark to wrong student	11	0.09	11	a): delete data in O, U, V, AB; if mark 5, + select row, set font 10 b): delete data in columns Q, X, AC, select row, set font size to 10
Problem finding student's record	74	0.60	74	More time spent visually scanning.
Unresponsive application or device	3	0.02	3	Wait or reboot device
Network connection lost	1	0.01	1	Wait or contact tech support
Slow response from the app, reloading and focus lost	2	N/A	0	Bug in Google Drive , workaround had to be implemented
Note inserted in mark column for wrong student, overwrites the final mark, not detected immediately	2	0.02	0	Web interface, previous versions
Student was late, allowed to work, but his record is too away from other active students	6	N/A	0	N/A (be aware of particular student) - Limit of the design.
TOTAL	**177**	**1.3**		

* Solved by the user on detection, using tablet interface

Flexibility makes application for small user base cost effective when developed on spreadsheet platform. Adding feature of multiple simultaneous users with WEBDAV technology, provided by many cloud providers, additionally increases usage possibilities.

The most serious risk of exposing all the data to the user with spreadsheet platform is a risk of destroying data by accident. Only immediate detection of error can be solved with undo command. Users usually solved these issues by manually entering correct data again. In certain cases, it was necessary to make the correction inside instrumentation columns. During our study, in two cases accidental errors resulted in invalidation of large amount of data. Users were able to recover data using Revision history mechanism available in Google Drive web interface. Other most common errors were editing or insertion data for the wrong students, and users were able to successfully resolve them.

Other issues are not directly related to the application but to underlying technology. After an update, referencing between sheets didn't handle well in the Google Docs Spreadsheet application which resulted in reloading of the whole spreadsheet on every editing of data. The functioning of permanent internet connection can sometimes be serious source of problems as the platform is highly dependent on the continuality and quality of Wi-Fi connection, but in our study, there were only one short disruption in connectivity.

Having in mind intensity of interactions between students and teachers during lab practicing and complexity of teachers duties, overall recorded problem occurrence ratio can be considered very low, while successful resolved problems ratio extremely high, leading to conclusion that management application design and implementation succeeded to achieve satisfactory level of robustness. We also found that user tiredness significantly affects performance when using dashboard interface for weaker implemented functionalities that relay on visual scan. For that reason, in future development, alternative methods for potentially problematic tasks can be provided.

We have demonstrated in this study that, with careful design driven by feature set limitations of the platform, dependable and effective application can be developed on spreadsheet platform, for use in very complex environment of lab practicing.

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