Promoting Active Learning in Large Classrooms: Going Beyond the Clicker

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Abstract. Teaching and learning in most current university lectures has remained unchanged for centuries and nowadays, large lecture classes are a fact at universities. Technologies such as Classroom Response Systems have been designed to ease the adoption of new pedagogical practice in these contexts; however, these pose technological, economic and pedagogical limitations to teachers, students and institutions. In this paper, we present a feasibility study of a system that allows students to take snapshots of paper-based, handwritten solutions to a given task with their devices, and then converts this input to vector graphics that are automatically hosted in a cloud-based storage service, such as Google Drive. The teacher can then discuss students' solutions and provide elaborate formative feedback in class. We report on the findings of a feasibility study with engineering students in Chile, which validate the practicality of the approach. After this validation we plan to integrate optical character recognition capabilities in the system, in order to support programming and physics education.

Keywords: BYOD · Classroom Response System (CRS) · Active learning

1 Introduction

The educational process carried out in brick and mortar university classrooms has remained almost static for the last couple of centuries [1]. This obliviously neglects a wealth of research evidence indicating that not all students can learn effectively through the same learning experiences and at the same pace [2]. In addition, ascertaining students' mastery of the expected learning outcomes requires conducting effective assessment [3]. With regard to assessment, high-stakes testing that is usually conducted in Chilean university education poses two major problems:

1. The time span between successive assessments is too long (i.e., many weeks or months), thus the teacher remains unaware of students' learning performance for most of the academic term.

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2. It is common that teachers themselves do not revise and grade students' summative tests due to the large amount of time this process requires. Instead, teaching assistants usually conduct this work for them. As a result, teachers do not become aware of students' common misconceptions, errors and lack of learning, thus continue to repeat ineffective teaching strategies term after term.

Both problems mentioned above, together with the assumption that all students do not learn at the same pace, calls for solutions that can provide the university teacher continuous awareness on students' learning progress, and the possibility for him/her to provide the students timely feedback that can effectively address learning issues. One way in which such solutions can be implemented is through embracing Active Learning (AL) in the classroom [2]. With AL the teacher conducts hands-on activities with the students, improving their motivation and understanding compared to traditional lecturing [4]. Moreover, through observation of students' results in the classroom, the teacher is able to discern the extent to which students have mastered expected learning outcomes. It is therefore a common practice to conduct formative assessment activities in AL contexts, enabling the teacher to become aware of students' common misconceptions, errors and lack of learning, and take prompt remedial action. According to the literature [1, 3], formative assessment activities in university classrooms consist of low-stakes tests conducted with following procedure: (1) The teacher presents the problem statement to the students. (2) The students try to solve the problem either mentally if the problem's cognitive requirements are low, or by sketching the solution on paper and pencil if more complex knowledge representations are needed to solve it. (3) The teacher will have a quick look at students' responses and spot any common misconceptions or errors. (4) The teacher provides feedback addressing learning shortcomings through further explanation and examples.

Analyzing this procedure, we can see the limitations that arise when embracing active learning and conducting formative assessment activities with large cohorts and no technological support. Firstly, management issues arise, as the teacher requires quick collection of students' responses and selecting those that can provide evidence for learning misconceptions and shortcomings. Secondly, the teacher needs to draw on students' responses to show and comment on students' own mistakes or achievements, and s/he has no convenient way to display (project) students' solutions at a large size in the classroom, and to edit and combine students' responses.

In the past, various systems have been developed allowing students to work on computer-based "documents" or "electronic worksheets". These technologies enable the teacher to monitor students' in-class work [5–7]. However, most of these systems have been used with small cohorts, as the activities require 1:1 computer-student settings which are difficult to scale to large classrooms [6]. Classroom Response Systems (CRS) [8, 9] have been used for fostering students' participation in class, by introducing some kind of technological device for the student to deliver an answer to a question or problem posed by the teacher. Commonly, closed-ended or multiple-choice questions are posed to the students, rather than open-ended questions and tasks that prompt for more elaborate responses requiring more sophisticated knowledge representations [10].

In this work, we present a feasibility study of a CRS system that allows students to submit pictures of their work to the teacher by using the camera on their mobile phone.

The system transforms the handwriting and sketches contained in the pictures to Scalable Vector Graphics (SVG), which the teacher can further edit and combine with a tablet device or an interactive whiteboard, to provide feedback to the students in formative assessment activities. Furthermore, SVG facilitates enabling automatic handwriting recognition, which could be used to input students' responses to third-party applications, such as simulation software, or a programming language. The abovementioned process can be implemented in a technology-enhanced manner as follows: (1) The teacher presents the problem statement to the students. (2) The students try to solve it using pencil and paper. (3) Upon completion of the exercise or the time set for the exercise, students capture an image of the response with their smart phones and send it to the system for processing. (4) Once the images have been processed, the teacher reviews the answers on his tablet, selecting a set of them that can serve as a basis for carrying out the next step. (5) The teacher proceeds to the discussion, feedback, evaluation, analysis and storage of students' responses and elaborates feedback for the students.

The following sections present a review of related literature, an account of our feasibility study that includes a description of the system, the results of the study and prospects for future work.

2 Related Work: Active Learning in Large Classrooms

Although large classrooms are cost effective, they have many disadvantages for learning [8]. Attempts to offset these problems include implementing participative learning methods, such as in-class problem solving, case studies, and peer discussion. Technology has been used to support these efforts. In particular, the term Classroom Response Systems (CRS) [9] refers to technology which allows a teacher to present a question or problem to the class, students to enter their answers using some kind of device, and then aggregates and summarizes students' answers instantly. An interesting example is Eric Mazur's experience with Peer Instruction in physics education at Harvard [11, 12]. Regarding CRS, studies have reported greater levels of student motivation [13], better student understanding [13], increased classroom attendance, higher student performance, improved student participation in class [4, 12], support for collaborative learning activities [12], and enhanced learning in the classroom [10, 15]. The main goal of a CRS has been to increase student engagement, especially in large classes where students may feel disconnected and anonymous [8, 16].

According to [14], four different CRS-type technologies have been applied in large classrooms to collect students' instant responses: (1) low-cost, low-technology tools such as hands, flashcards, color cards, or whiteboards (2) instant response systems: such as numeric keypads, interconnected by hard-wired equipment. (3) wireless radio frequency or infrared devices, which resemble a TV remote control. (4) wireless network-based systems and so-called *Bring Your Own Device* (BYOD) settings [17], i.e., smartphones can be used as answer devices, and an application can quickly scan and collect students' answers. Positive effects of CRS on student's cognitive abilities like critical thinking, problem solving and metacognition have been reported in [14].

Despite the significant benefits reported, CRS have some disadvantages too. Despite the ease of use of the technology and the benefits that they provide, faculty members may be reluctant to introduce new technologies in class and may perceive high costs in terms of time and effort investments. In addition, similar to other advanced technologies, CRS can generate frustration and unsatisfactory situations due to technical issues like failures or bugs [10].

Nowadays, the need for collaborative learning inside of classroom, around data-sharing, is understood as a fundamental basis to incorporate suitable collaborative learning activities, to bolster student success [17]. The BYOD movement calls for enabling students to perform learning activities by using the technology with which they are already familiar. This permits students a greater sense of ownership over their learning, brings productivity gains and fosters ubiquitous learning.

3 Feasibility Study

The system here proposed is illustrated in Fig. 1, and it works as follows: The teacher poses a task for the students to work on in class (step 1), then the students write down their solutions to the task on paper and take a picture of it with their mobile phones (step 2). Thereafter the students submit the solution to a web application (step 3). The web application issues an asynchronous processing job to an image processing RESTful service that corrects (i.e. crops, rotates, and adjust image levels) and converts (i.e. binarizes and vectorizes) the original bitmap image. When the resulting vector image is ready, the web application is notified by the service and then the vector image is uploaded by the web application to a cloud-based storage service, such as Google Drive or Dropbox. In step 4, the teacher can review the solutions submitted by the students, and then conduct a discussion viewing, editing, combining different solutions using any vector illustration application available in his/her mobile device (step 5).

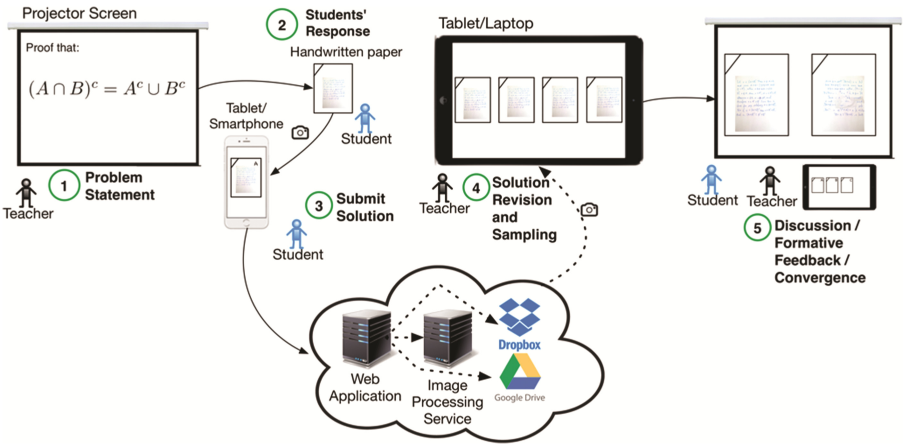

Fig. 1. The system is composed of a web application that hosts the user frontend, and an image processing service that corrects and enhances the source image, and cloud-based storage.

We conducted an initial trial of the system involving a cohort engineering students at Universidad de los Andes, Santiago, Chile. The trial comprised two activities based on logic problems, which were conducted with the intent to evaluate technological features and pedagogical usability of the tool; namely, we sought to assess the quality of the SVG digital sketches produced by the image processing algorithm embedded in the system, the practicality of the tool in the classroom from the students' standpoint, and validating the digital affordances offered by the tool to the teacher, to conduct discussions examining students' sketches on a tablet device.

The trial was conducted in a classroom equipped with a full HD projector, a WiFi access point, an AppleTV device and mobile chairs with swivel tablet arm.

3.1 Sample Description

Seven engineering students attended the trial activity. Six of them majored in computer science, and one in electrical engineering. All the students were male with ages between 22 and 25 years. The mean age of the group was 23.9 years. Every student in the sample owned an iOS or Android smartphone with photo camera.

An engineering thesis student took the teacher role in the activity. He used a 12-inch iPad Pro device to monitor students' activity and discuss their solutions to the tasks comprised in the trial. The AppleTV device in the classroom was used to stream the iPad's screen contents to the projector in the classroom.

3.2 Procedure

Firstly, a short briefing was delivered by the teacher to the students, which included an overview of the system and an explanation about the learning flow of the activity. The students were also given some hints on how to take appropriate pictures of their handwriting on paper, with suitable lighting and framing. Then they were instructed to open the solution submission site in the web browser in their smartphones.

After the briefing, the teacher presented the first task to the students on paper. The task was based on a puzzle problem based on the popular game Strimko. The students had to solve the puzzle with paper and pen, which involved drawing a graph with several numbered nodes and edges. When a student finished writing his solution, he was required to take a picture with his smartphone and submit it through the online submission form. In the meantime, the teacher automatically received the students' solutions as SVG illustrations in a Google Drive folder (see the conversion process in Fig. 2), which he could check on his iPad device with a vector illustration application. Once all the students submitted their solutions, the teacher continued to present and discuss the students' different approaches to solve the problem. He managed to edit students' solutions in the application, with digital handwriting on the iPad device.

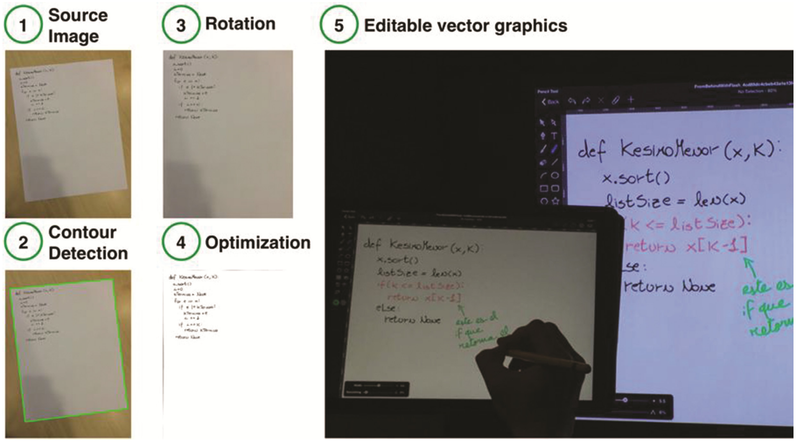

Fig. 2. Steps to students' automatic response digitalization and conversion to vector graphics.

The second task of the trial was about solving a logic puzzle. The puzzle was presented to the students in narrative form, which included a partial solution. It was the students' job to find an explanation for such solution, and state the explanation in either verbal language, formal logic or both. The same learning flow described above was conducted, with the activity ending with a discussion mediated by the teacher.

At the end of the activity a survey was administered, with the aim to collect students' appraisal and impressions about the trial and practicality of the tool in the classroom.

3.3 Results

The items and results of the survey conducted at the end of the trial are shown in Table 1. The responses to the first two questions were unanimously affirmative and ascertain that the initial instructions in the briefing were clear to all the students. The responses to questions 3 and 4 show that some students had difficulty taking a good picture with the smartphone, however, uploading the picture to the system once taken was easy. The quality of the processed images displayed on the projector screen was very good (question 5), and the students liked the methodology and considered its implementation in engineering lectures feasible and desirable (questions 6–8, and 10–12). However, only 5 of 7 students had their solutions selected for at least one of the discussions and therefore displayed on the projector screen (question 9). The students consider that the system could be useful for both regular lectures and recitations (question 13), and that keeping the original solution submitted by the student and the solution modified by the teacher would be beneficial for learning (question 14).

Table 1. Results of students' survey.

#	Question	Answers	M (SD)
1	Were you able to understand the instructions given at the beginning of the trial for taking pictures with your smartphone?	No (0), Yes (1)	1.0
2	Were you able to understand the instructions given at the beginning of the trial for submitting your responses to the teacher	No (0), Yes (1)	1.0
3	What is the difficulty level of taking a picture of a handwritten solution on paper with your smartphone?	Five-point Likert Scale (LS) 0: Very difficult 5: Very easy	3.86/5.00 (0.49)
4	What is the difficulty level of submitting pictures taken with your smartphone to the teacher?	Five-point LS 0: Very difficult 5: Very easy	4.29/5.00 (0.76)
5	How does the digital version of your response presented by the teacher in the discussion resemble the original response you wrote on paper?	Four-point LS 0: Very poorly 4: Very well	3.71/4.00 (0.49)
6	Did you like the activity?	No (0), Yes (1)	1.0
7	Do you think the methodology used in the activity could be implemented in engineering classrooms?	No (0), Yes (1)	1.0
8	Would you like to participate in regular classes with this methodology?	No (0), Yes (1)	1.0
9	Was any of your responses selected in the discussions conducted in the activity?	No (0), Yes (1)	0.71
10	Do you think this methodology could facilitate teacher-student communication in the classroom?	No (0), Yes (1)	1.0
11	Do you think this methodology could facilitate student-student communication in the classroom?	No (0), Yes (1)	1.0
12	Do you think this methodology can improve learning of certain contents?	No (0), Yes (1)	1.0
13	In which of the following contexts do you think this methodology could be beneficial? (1) Problems in class about new contents, (2) Problems in class about previous contents, (3) Recitation problems	Multiple-choice	Choice frequency: 1:3 2:5 3:5
14	Which of the following solutions can be useful for students' further analysis and study after discussion? (1) Only the original version, (2) Only the modified version, (3) Both versions	Multiple-choice	Choice frequency: 1:0 2:2 3:5

The teacher was able to conduct the activity with no technical issues or errors. He could access the students' solutions automatically copied by the system to his personal Google Drive folder and display them in the illustration application on the iPad Pro device with ease. The students' solutions were highly legible.

4 Conclusions and Future Work

The CRS system presented here allows students to submit solutions to open-ended problems proposed by the teacher using their own smartphones, and in a very simple fashion. The teacher has the possibility to review (at least a sample of) students' solutions and provide elaborate feedback in the classroom to address students' common misconceptions, errors, and analyze different ways to solve a given problem. This procedure is easily scalable to large classrooms, allowing students to actively participate in lectures. At this stage of our work we successfully tested the system with a small cohort of engineering students, evincing that the technology can support active learning activities with formative feedback with use of student-owned smartphones. In addition, the technology supports the teacher in elaborating feedback based on students' handwritten responses.

After completing our first proof of concept, through which we have managed to digitize students' handwritten responses, obtain clearly legible and editable vector graphics, and have the solutions automatically stored in a cloud-based storage service, our future efforts will aim at applying optical character recognition to students' handwriting, in order to use students' handwritten text and sketches as input for a programming language interpreter, such as Python, or a physics simulation software. In the case of programming education, the system opens the possibility to lively test students' original handwritten code on paper, modify the code (e.g. merge code from different solutions, or debug the code), and distribute the code back to the students. On the other hand, mechanics simulation could be possible by means of stating movement equations and sketching the bodies in motion on paper. From a more general point of view, we envision that our system will evolve towards becoming a general means for seamlessly converting students' and teachers' contents generated with paper and pen to digital learning objects, and in this way augment teacher's possibilities to elaborate formative feedback for students in lectures, beyond what is possible with the conventional clicker-based CRS.

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