Supporting Active Learning through Commodity and Open Source Solutions

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***Abstract*— Active learning has demonstrated value in STEM education and various meta analyses show improvements in student performance when making use of active learning pedagogy and active learning classrooms. One limiting factor to extending the reach of active learning is cost. Many models for state-of-the-art active learning environments make use of tools and infrastructure through which students can connect their own devices and share their digital artifacts in real time with their teammates and the entire class. For computing disciplines, the desire to make use of this type of technology is intuitive as it allows students to see alternative solutions, inspire confidence in student capabilities and can mimic pair programming practices used in industry. Still, retro fitting existing spaces or new construction of state-of-the-art active learning environments and the installation of standard, supporting technology can be cost prohibitive for many institutions, indicating a need for alternative implementations to active learning technology which are applicable to a wider audience. In this work we describe the construction, use and initial evaluation of commodity hardware and open source software to support active learning which we term Practical Active Learning Stations (or PALS).**

Keywords—active learning; educational technology

I. INTRODUCTION

Active learning can be considered activities that involve students in the learning process so that they take part in the construction of their knowledge and understanding as opposed to largely being passive recipients [1]. Several studies and meta analyses of the literature have linked active learning to increases in STEM student performance and increased classroom satisfaction on the part of students [1], [2]. Often times, active learning pedagogy is supported through the use of specific technologies or classroom environment [3]–[6] and while active learning can be accomplished in a traditional classroom without additional technology, having the right support for active learning aids collaboration and interaction.

There are a number design patterns for active learning classrooms (ALCs) and supporting technology. Popular designs for active classrooms include SCALE-UP [7], TEAL [8] and varied implementations of these designs in place at many institutions of higher education [4]. These implementations commonly involve group seating, a centralized instructor podium and technology to support collaboration and look quite different from a traditional classroom. As a result, new construction or extensive renovations are often needed to create ALCs. Nevertheless, learning spaces could make use of mobile computing devices (e.g., computers on wheels) [9] or use web-based technology (e.g., Google Docs, simple screen sharing tools) as an alternative to expensive renovations and these types of approaches to support active learning represent the other end of the spectrum in terms of cost.

In this work we describe the construction, use and initial evaluation of commodity hardware and open source software to support active learning. Cost is arguably the largest obstacle to deploying more active learning technology or creating more active learning spaces. The system described here is economical, flexible and extensible and offers a number of useful extensions. The base cost for this system can be as low as $300 per student station.

II. PRACTICAL ACTIVE LEARNING STATIONS

Ten units, which are termed Practical Active Learning Stations (or PALS), have been constructed and deployed in an introductory computer science course (i.e., CS1). Each unit consists of a 23” LCD with an enclosed micro ITX form factor PC mounted to the back. A HDMI capture dongle is installed on each station to mirror locally the content that is received via the HDMI input. The station can also be used to broadcast content to larger displays or an instructor station. Each station communicates to an instructor station on a regular interval, sending a screenshot of the content being displayed locally. The instructor can view all of the screenshots of the student stations via a web portal and is able to select a station and stream the student content to large LCDs deployed through the classroom. Both the student and instructor stations are based on Linux and FFMpeg is used for video processing and streaming. Fig. 1 illustrates the major components of the PALS system.

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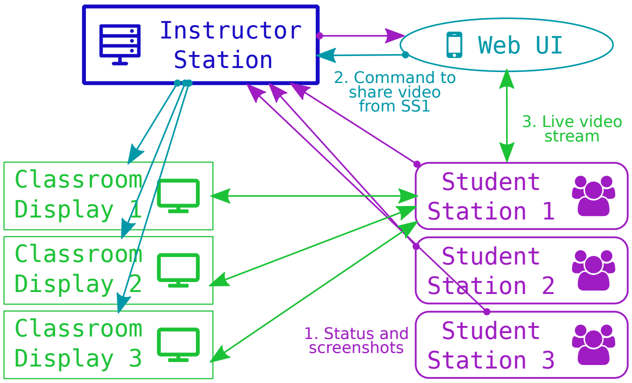

Fig. 1 Illustration of the overall architecture of the PALS system.

A. *Student Station*

Student stations are the main distributed component of the PALS system. They are Gigabyte motherboards in Mini-ITX enclosures, mounted directly to the back of 23" monitors. Video capture is done via an external HDMI-to-USB capture dongle. A small wooden frame is used to mount the major components and anchor the power/network/video cables, so that each student station can be carried in one hand. Since they do not have any user-visible state for the students to configure, student stations are not deployed with keyboards or other non-video input devices.

The student stations run the minimal variant of CentOS 7. The system boots directly into a restricted user session. A background service is used to mirror video input from the HDMI-USB capture dongle to the monitor using ffplay (and other supporting software and kernel modules). Other background services are used to mirror of the video input as an HTTP video stream via ffserver, to periodically send screenshots to the instructor station, and to collect diagnostic data. Software configuration is done through a combination of puppet and bash scripts. Fig. 2 shows a PALS unit and a larger classroom display consuming content from a laptop.

Fig. 2 Notebook computer attached to a student station (left) and broadcasting to one of the larger displays (background).

B. *Instructor Station*

The instructor station is the central server of a PALS classroom. It is a Rasberry Pi running Rasbian Linux. A background service hosts the PALS WebUI server. The instructor may attach a keyboard, mouse, and monitor/projector to the station and access the WebUI via local web browser, or they may connect remotely from a personal device. The instructor station uses mDNS to advertise a local domain name in the reserved ".local" TLD. This allows other devices, including the student stations and instructor devices, to establish connections to it without the need for static IP addresses or centralized PALS "master" servers. mDNS has limitations, however. The most problematic is that all devices must be on the same local network, which is not always possible in practice.

The WebUI itself is a basic web app running on Node.js. Student stations advertise themselves by sending screenshots and some status metadata, which the server forwards to connected WebUI clients. Clients may browse and save screenshots as they arrive. They may also nominate to share the live video feed from one student station with the entire classroom. The WebUI operates on a mostly REST-ful API, with websockets used to push update notifications from the server.

C. *PALS Classroom Environment and Instructor Remote*

The PALS system was routinely deployed in a classroom which had been modified for use with the system. The modifications included arranging the desks into pods and placing them around the periphery of the room. The instructor's podium was also moved against the wall. Large LCD TVs were placed on wheeled carts and located throughout the room. Each pod hosted up to 2 PALS student stations and all of the devices communicated through a local area network already installed in the classroom. Fig. 3 depicts the overall layout of the PALS classroom.

To promote range of movement for the instructor, a mobile application is currently being developed to allow the instructor to select and display student content from a mobile device (e.g., tablet or smartphone). It should be noted that since the interface on the instructor station is web-based, an instructor can already control the system through a mobile device if it equipped with a browser and connectivity to the instructor station.

D. *Functionality of the PALS System in the Classroom*

The PALS system allows students to collaborate in multiple ways. First, a student connects his or her device to a PALS unit and the entire group is better able to see the development of code or any digital investigation. Second, the instructor is able to view students' progress on any PALS unit by viewing the instructor remote or a web browser on the instructor station. Content can be selected and pulled from any of the PALS units and immediately broadcast to the larger displays throughout the classroom so that a particular group can quickly and easily share their solution with others.

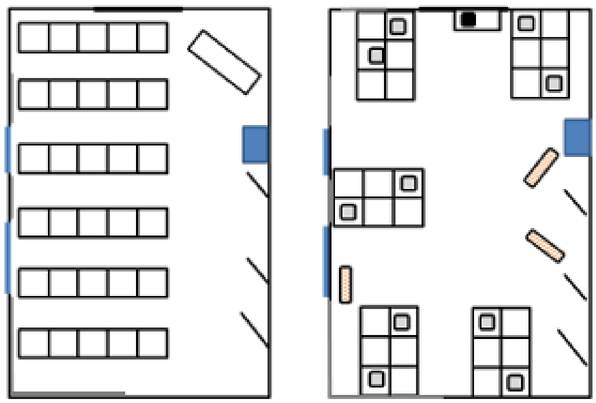

Fig. 3 Modifications made to the classroom with the previous layout on the left and the PALS layout on the right. Detached rectangles represent the location of the large LCDs.

In addition to the base functionality previously described, the PALS system is able to support communication in ways in which typical ALC technology cannot. The student stations regularly capture and share screenshots of local content with the instructor station. As the instructor is monitoring student progress through the instructor station (or remote tablet, etc.), these screenshots can be tagged, stored and shared at a later time. Additionally, the screenshots from each PALS unit are saved locally and converted into a video that the instructor can view. This allows the instructor to monitor time on task or go back and diagnose difficulties that a particular group may have encountered. Finally, the PALS units, as a video capture, encoding and distributing device, could capture video from a locally connected camera and provide students with a document camera to share analog artifacts.

III. Discussion

A. Comparision to Existing Technology to Support Active Learning

In terms of its ability to share student content, the PALS system is similar to general screen sharing software or hardware (e.g., Zoom, AirMedia, etc.) but differs in several ways. Note that no software or configuration is required on the part of the student's device. The device is simply connected via HDMI and it works. Furthermore, the local display provided by each PALS student station supports local collaboration and the instructor has the ability to view and monitor all connected content being displayed locally. The instructor can immediately share that content through larger displays or archive screenshots or views of student work.

In comparing the PALS system as deployed in this work with standard active learning classrooms there are a few notable differences. First, there are more local displays (i.e., 1 per group when 1 per table is the norm for many ALCs). Additionally, with a larger number of local displays, smaller groups can be formed with each group having more privacy. It was not possible to move the instructor station to the center of classroom so it remained in the front of the classroom. Other than these differences, standard ALCs and the PALS classroom function similarly, supporting student collaboration, the instructor's ability to interact and move about the space and quickly sharing students' digital artifacts.

Another suitable point of comparison are flexible collaborative learning spaces such as those in use at Queensland University of Technology in Australia. These spaces make use of wheeled tables, chairs and computers on wheels (CoWs)[9]-[11]. A CoW includes a web-enabled computer, large touch-screen, whiteboard, table, and six chairs. All of the hardware is on wheels so that classrooms using CoWs can be quickly reconfigured for the activity at hand. Each CoW is nominally independent and for communication the emphasis is on internet connectivity. Students can connect their devices to a CoW to share content locally and the wheeled nature of the tables, chairs and technology allow it to be deployed in a number of seating configurations [10]. PALS differs in that the student stations are much more inexpensive to construct and allow the instructor to monitor, capture and share student content through the larger displays throughout the classroom. Both systems are flexible enough to be deployed in different configurations and support local and class wide collaboration, but to different degrees and by different mechanisms.

B. Design Considerations

The grade of the hardware selected has a considerable impact on the overall cost of the system. For the large LCDs, professional/commercial grade can be 3 times the cost of consumer grade. If implementing a dedicated active learning classroom, then commercial grade would be warranted. For the student stations, economy grade hardware or retired workstations are sufficient. For the student stations assembled in this work, the cost was roughly $700 per unit (including the Magewell HDMI capture dongle). The PALS software stack was also installed on two older hardware configurations (e.g., Dell OptiPlex 790 and iMac "Core i5") and both machines performed well.

Complementary to the design of the PALS systems is the layout of the classroom in which it is deployed. The PALS system is designed to leverage the existing infrastructure of a classroom as much as possible. As a result, the output of the instructor station ties into the existing audiovisual system already in place. Most existing network architectures should be able to handle the load generated by the PALS system. Ideally, the seating in the classroom should be rearranged to accommodate group seating.

The PALS system is very flexible by design and could be deployed in a number of settings. The student stations and larger classroom LCDs can be installed in a designated lab and affixed to the walls or the system can be distributed as needed and collected after each class period (as used in this study). Due to the licensing of the software that is used and HDMI capture to USB dongle, the PALS software stack is flexible enough to be installed a variety of hardware. Furthermore, the Bring Your Own Device (BYOD) model employed here ensures that students can use the development and research tools they choose and they do not need to install any particular software to use PALS. They simply connect their device via HDMI and PALS is capable of consuming and sharing this digital content.

C. Resources

Because PALS involves streaming media, it can be quite resource intensive to operate. Each student station sends a 1280x800 screenshot to the instructor station at regular intervals, producing periodic bursts of network traffic. With a conservative screenshot interval (~10s), this generates about 3kbps of background network traffic for each idle station, and about 300kbps of network traffic for each station that has a student computer plugged in to the HDMI cable. This traffic is all directed to or from the instructor station.

When the instructor elects to share a student station, each of the classroom displays establishes an independent HTML video stream from that station. With three displays, this generates an average of 12Mbps additional network traffic, and can generate bursts up to 25Mbps. This represents a significant fraction of the available bandwidth for current generation wifi (802.11n offers up to ~150Mbps in the older 2.5GHz range, and 802.11ac offers up to ~800Mbps in the newer 5GHz range). While a single PALS classroom can run comfortably on a dedicated wifi network, scaling to many classrooms on a shared wifi network may require changes in the distribution of shared content to the larger displays (e.g., HDMI splitter and wired HDMI over Cat5).

CPU Utilization on the student stations is much less varied; hovering between 40% and 50% depending on whether or not the station is actively streaming.

IV. Initial Evaluation

In Spring 2017, one class utilizing the PALS system was tested as part of our initial data collection. The results of this initial deployment of the PALS were compared against an active learning classroom. Both sections of the same course were taught by the same instructor with similar pedagogies that included active learning techniques such as think/pair/share and group programming activities). Initial collection efforts incorporated a pre-post survey design where an external evaluator (and fifth author of this manuscript) collected data while the instructor was not in the room to reduce conflicts of interest and encourage more honest responses from students. The instructor also had no knowledge of which students elected to participate in the study.

The initial data collection netted a response rate of 64.4% (*n*=29/45) for the active learning classroom, while the PALS classroom had a response rate of 92% (*n*=23/25). To measure the impact of using an active learning classroom versus a PALS classroom, students completed a short survey in week 13 of the course. The three questions examined in this initial manuscript were: (1) "To what extent did using the available in-class technology enhance your ability to collaborate and work with your peers?", (2) To what extent did screensharing (i.e., the ability to share your screen with your group of the class) enhance your ability to collaborate and work with your peers?", and (3) To what extent did screensharing (i.e., the ability to share your screen with your group or the class) enhance your learning?" Responses were chosen on a 4-point Likert Scale, ranging from 1-4, with 4 as To a Great Extent, 3 as Somewhat, 2 as Very Little, and 1 as Not at All. Mean scores were calculated for each of the three questions. A two-tailed independent-samples t-test using a 95% confidence interval was used to determine if there were significant differences between students' self-reported scores on the effect of the screensharing technologies on the three items listed above [12].

The results of the independent t-test indicated no significant differences between the active learning classroom and the PALS system on the three measures related to students' assessment of the impact of the technology on their ability to work with peers and learning.

Question 1: Active Learning (μ=3.24, SD=0.87) and PALS (μ=3.34, SD=0.71; $t(50) = -0.47$, p =0.64, two-tailed). Result: no significant differences.

Question 2: Active Learning (μ=3.17, SD=0.85) and PALS (μ=3.08, SD=0.67; $t(50) = 0.40$, p =0.69, two-tailed). Result: no significant differences.

Question 3: Active Learning (μ=3.04, SD=0.91) and PALS (μ=3.43, SD=0.66; $t(50) = -1.78$, p =0.82, two-tailed) Result: no significant differences.

The survey also allowed students an opportunity to provide open-ended feedback about the impact the in-class technology had on their learning. For students in the active learning classroom, 28 students responded to this question. The majority of them (79%, *n*=22) indicated a positive effect, noting the technology played an important role in their learning. The results were similar to students in the PALS classroom, where 83% (*n*=20/24) indicated the technology had a positive impact on their learning. These open-ended responses were categorized using an open-coding scheme that were broadly categorized into three categories: positive effect, negative effect, and no effect.

These results, although initial and based on a limited sample size, indicate that the PALS system may be capable of replicating similar results to active learning classrooms related to enhancing collaboration and positively affecting learning.

V. Conclusion

In closing, commodity (or repurposed) hardware in conjunction with open source software can be an economical option to support active learning. Systems such as PALS can aid in student collaboration and help the instructor better monitor and share exemplary work. Its lightweight footprint, mobile nature and flexibility mean that it and systems like it can be deployed in classrooms with minimal changes needed to the underlying infrastructure.

Acknowledgment

This material is based on work supported by the National Science Foundation under Grand No. 1608043.

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