Learning On and At the Edge: Enabling Remote Instructional Activities with Micro Controller and Microprocessor Devices

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ABSTRACT

As a result of the global pandemic of 2020, many colleges and universities shifted to remote instruction. Thanks in part to the reliance on cloud-based hosting for mission-critical enterprise systems (e.g., enrollment, library collections, learning management, and video-conferencing), most higher education institutions have been able to continue teaching and learning activities overall in this difficult context [1]. For a small but important subset of courses, however, the lack of access to laboratory, workshop, or studio spaces has presented enormous obstacles to carrying on [2]. The negative impact to hands-on instruction has been a major preoccupation during the pandemic, but there are some signs of hope. As we'll see, inexpensive microcontroller and microprocessor systems and accessories have emerged as enabling technologies that show promise as a solution for carrying on certain kinds of remote hands-on activities. This paper looks at three situations where instructors were able to overcome the challenges of remote instruction by being able to distribute kits and digital lab materials to students for remote work using devices such as Arduino, Raspberry Pi, and NVIDIA Jetson. The three examples suggest a potential role for academic computing services in being able to scale up these sorts of device-based solutions to achieve broader impact.

CCS CONCEPTS

• **Applied computing** → Education; Interactive learning environments.

KEYWORDS

Academic Computing Services, Remote Instructional Activities, Microcontroller Device

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1 INTRODUCTION

Among the dramatic interruptions in higher education brought on by the COVID-19 pandemic in 2020, the shift to remote instruction particularly impacted hands-on learning activities typically

carried out in venues such as laboratories, workshops, and fabrication shops [3]. While virtualization and simulation software provide some partial relief for alternate lab activities, certain hands-on activities can also be recovered or recreated, it turns out, by providing students with low-cost digital electronic devices and kits for home use. Devices such as Arduino, Raspberry Pi, and NVIDIA Jetson were already seeing use on campuses before the pandemic, of course. In the pandemic crisis, their relative low-cost, ease-of-use, and availability have allowed for rapid deployment and use in remote learning activities, as schools find ways to pivot activities for individual use in students' home settings.

This paper surveys several examples where these devices made innovative remote alternatives possible and considers how these successes might be expanded. These cases suggest opportunities for educational technology service providers to support these technologies with the aim of offering scaled-up resilient remote instructional arrangements in many more courses during future crises. In particular, the paper's goals include: 1) describing several use cases in which deployment of these sorts of devices allowed instructional activities to continue during remote instruction; 2) examining the category of low-cost microcontroller and microprocessor devices and their potential in different courses across the curriculum; and 3) considering the service opportunities for improving processes and support if this technology category to scale up in support of more resilient curricular alternatives for the future.

2 BACKGROUND

Surveyed below are several instances of a trend observed in the 2020 spring, summer, and fall terms at UC Berkeley where inexpensive microcontroller and microprocessor devices enabled solutions for remote hands-on learning during the pandemic situation. Maker kits, Internet of Things (IoT), Embedded, and Edge Devices are some of the terms that gloss the categories devices deployed in the cases described. Such devices have been in common use on campuses during the past decade, although they have not necessarily received much attention from a computing services perspective. More prominent developments such as data science, machine learning, and robotics have tended to grab the headlines in higher education in recent years. Still, in the shadow of these better-known areas, a thriving ecosystem has sprung up of affordable computing devices along with a remarkable variety of connectable sensors and actuators and sundry other peripherals. The biggest educational impacts of these devices are typically found in STEM curriculum. Related and overlapping technology areas — maker electronics, IoT, and edge computing — also involve interesting mixes of these same devices and platforms from which data and information processing can flow from a two dollar sensor through a microcontroller all the way to high-end computing clusters in the cloud [4].

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Figure 1: Arduino Uno and its many pinouts. [Public domain], via Wikimedia Commons. <https://commons.wikimedia.org/wiki/File:Arduino-uno-pinout.png>

3 CASE STUDIES

It's important to note that the following case studies reveal as much about the ingenuity and dedication of the instructors involved as they do about the enabling capabilities of the technology involved. These cases hint at opportunities for potentially scaling up use of these technologies in support of remote instruction in future crises. In the context of a planned instructional computing support, this technology ecosystem of inexpensive microcontrollers, microprocessors, and their many connectable sensors and probes could provide sustainability and continuity for a significant amount of hands-on teaching and learning activities across the curriculum.

3.1 A Physics Lab in the Mail

It is difficult to imagine a more rapid or heroic way to salvage a course than this first example. As the COVID-19 pandemic hit in the winter of 2020, UC Berkeley's fifteen-week Spring semester was underway. The Donald A. Glaser Advanced Instrumentation Laboratory at UC Berkeley supports the activities of advanced undergraduate Physics students in undertaking a series of multi-week laboratory experiments. The instrumentation lab projects cover

basic design, analysis, and modeling of circuits, and data analysis and control with in-person activities involving linear circuits, semiconductor diodes, JFETs, Op-Amps, and signal processing.

As UC Berkeley moved to shut down on campus activities in March, the semester was only half completed. With a half dozen lab activities still on the agenda, the course pivoted in the short term to using some simulation environments and videos. Meanwhile, the instructor in charge of the course personally undertook a rescue mission from his home. His solution to salvage the experimental component of the remaining labs centered on the deployment of Arduino microcontrollers along with resistors, capacitors, operational amplifiers, and prototyping boards. The instructor carefully assembled the individual lab kits at his dining room table. The sixty kits were then shipped out to residences all around the world, allowing the students to resume the hands-on aspect of labs for the remainder of the semester [5, 6]. Finally, it is encouraging to note that similar efforts using Arduino and Raspberry Pi devices for remote Physics labs were accomplished at other institutions as well during this period [7].

Figure 2: Example of an Arduino Accessory Bundle Kit. [Public domain], via Wikimedia Commons. https://upload.wikimedia.org/wikipedia/commons/5/5a/ARDX_-_Arduino_Experimentation_Kit_%28Inside_the_box%29.jpg

3.2 Prototyping Designs from Afar

While the previous example highlights one instructor's valiant emergency improvisation during the early days of the pandemic, the next example demonstrates the use of similar microcontroller technologies with a little more time to plan on remote instruction from the outset. The Jacobs Institute for Design Innovation at UC Berkeley supports a recent curricular trend driven by new emphasis on the design process and design thinking. Many of the Institute's courses make use of Arduino and Raspberry Pi as core tools for use in prototyping, as is common in maker and engineering curricula, [8].

For Summer Session 2020, the design courses previously scheduled for in-person hands-on activities were forced to go fully remote. Deprived of access to the well-equipped teaching, fabrication and workshop spaces around which many of them were normally organized, several instructors were still able to proceed despite the daunting constraints of fully remote instruction. Several design classes were conducted successfully during the summer even though the students were unable to set foot inside the Institute.

To compensate for remote instruction, the design course instructors and Institute staff shipped out bags of tools and materials that the students would need, including microcontroller and microprocessor devices along with various accessories needed for hands-on

activities. The management of this process was greatly aided by the fact that the Institute already had an existing inventory and storehouse that routinely furnished different models of Arduino and Raspberry Pi devices along with accessories (e.g., cameras, sensors, LED kits). It is also important to note that the courses involved had enrollments of fifteen to twenty student maximum. Not only does class size likely matter for material distribution but also for the extra effort required of the instructors to accommodate the remote student's individual circumstances in terms of access to computing resources and workspaces.

By the end of the summer, each student had learned enough at home to implement and demonstrate remarkably creative proof-of-concept designs and prototypes as final projects. Drawing on their choice of peripherals from stepper motors to LED display, the students controlled the actions and interactions programmatically using the Arduino development environment [9]. The final project showcase, which would normally have been held as poster sessions in person, was conducted via Zoom with each student having also prepared a write-up and recorded video. Giving a sense of the functional possibilities that Arduinos allow for, the final projects ranged from a smart shower water-tracking system to an interactive kinetic sculpture inspired by ocean waves. The creativity and technical sophistication of the final projects are even more impressive when considering that students were encountering Arduino

Figure 3: Sample race car chassis equipment layout. [Public domain], via Wikimedia Commons. <https://upload.wikimedia.org/wikipedia/commons/6/66/Mobile-robotic-car-MRC.jpg>

and its programming environment for the first time. Certainly, their success in being able to learn the technology while also planning and executing their projects should be credited to the instructor's scaffolding, the technical support offered by the Institute staff, but also in part to the user-friendly accessibility of Arduino [10].

3.3 Robots & Autonomous Race Cars Around the World

The final example is from fall 2020 and focuses on an undergraduate robotics course. In normal times, such a course would make heavy use of group projects carried out in well-furnished facilities where students would have round-the-clock access to tools, components, and computing resources to construct robots. For remote instruction during the pandemic, the instructors improvised in order to recreate as many aspects of the traditional course despite the constraints. In addition to adapting to online instruction overall, the major shift for the lab components involved reconfiguring the syllabus and lab activities to use a mix of simulation environments and low-cost kits.

The typical range of options for hands-on hardware-based projects in the course shows an impressive resourcefulness: micro-servo robotic arm, a table tennis ball bouncer, lightweight haptic devices, and Kamigami robot toys. Students are also invited to take on projects to develop miniature autonomous racing vehicles. In the race car projects, students develop a high-performance fully autonomous 1/10 scale RC car using NVIDIA Jetson microprocessor devices. The Jetson provides the graphical processing horsepower to enable machine learning and coordinated control of the car on a course via an attached digital camera and servo controls. As at many schools, the culmination for such projects can normally even lead to involvement in college-level racing competitions [11]. The popularity of these autonomous race car projects as extra-curricular activities among club or maker communities has also given rise to informal regional race competitions [12]. In order to promote these sorts of educational uses of machine learning, NVIDIA offers the Jetson Nano development edition for less than sixty dollars.

The inherently hands-on nature of the robotics course points to important challenges around supporting remote students outside of class time. When such courses are held in person, students normally have access to facilities and instructional support while doing their projects. With students working remotely, technical

and instructional support schedules become challenging, especially with students scattered across time zones. The faculty sponsors and instructional support staff are deeply involved in planning and pre-semester preparations. The use of robotic simulation environments (e.g. Gazebo, Carla) provide some fidelity to real world testing that teams would normally perform together in person during project development. Setting up and deploying these simulation environments for the remote students requires a significant extra effort. The use of the various platforms – Arduino, Raspberry Pi, and Jetson – requires a good deal of planning and scaffolding as well. Special effort is needed in determining how each student would use and interact with the provided kits in their home setting. As in the previous cases, this need for considering the resources individual students do and do not have access to in their remote setting potentially constrains the scale of such an undertaking for instructors. Much extra effort is needed in helping individual students use and interact effectively with the provided project kits outside of class time.

4 A ROLE FOR CENTRAL IT SUPPORT?

4.1 Service Possibilities

The students' need for technical support outside class time leads into the first of a series of questions that one might consider around a potential role for a central academic computing organization in supporting these activities more systematically and at scale. How might an IT Help Desk, for instance, play a role in providing after-hours consultation for students working through challenges with the technologies? Where the students' success in the three examples above stemmed from innovative instructors and excellent departmental support, what might be possible institutionally in cultivating and supporting this kind of activity with instructors who are less adept with the technology to start with or are based in departments with fewer resources? As with many educational technologies over the years, the path-breaking work of individual innovators often points the way to broader impact if only the initiative can be nurtured and supported institutionally. Academic computing traditionally plays the key role in promoting such new possibilities. Faculty development opportunities via workshops, demonstrations, and consulting comprise one traditional area of strength. Other examples include academic computing's role in making new activities secure and dependable via strategic sourcing, infrastructure provisioning and high-availability consulting support.

4.2 Devices & Accessories: Necessary But Not Sufficient

Before speculating further about potential roles, it is important to acknowledge the crucial enabling support that UC Berkeley academic computing services did provide in the background of the three use cases. The deployment of inexpensive sensors and computing devices to remote students obviously makes assumptions about what technology students have at hand in their remote setting. A microcontroller or microprocessors kits along with their various sensors is of no use if the student receiving them lacks access to a general-purpose computer with which to connect for programming and control.

Behind the scenes, academic computing services was busy accomplishing many extraordinary feats from the earliest stages of the pandemic. Even when the shelter-in-place order has just been issued, plans were already being drawn up for providing technology to students and instructors in need for home use. At UC Berkeley, the need to ensure that all students have reliable access to computers for success in the 21st Century curriculum in general was already the aim of a nascent equity program still being formulated when the pandemic struck. The pandemic crisis led to a rapidly accelerated timeline of the program in order to help students acquire computing equipment to use in their residences. Over the spring and summer months of 2020, a successful emergency effort was launched to make available thousands of loaner laptops, Wi-Fi hotspots, and other peripherals (e.g. webcam, headphones, etc.) in time for fall semester 2020 [13].

4.3 Strategic Sourcing, Consulting, and Training

With similar urgency, academic computing services also provided crucial guidance for instructors through crash course training and workshops for those who were less accustomed to teaching online. It is reasonable, therefore, to ask how an academic computing organization might go even further and draw upon its traditional strengths in order to scale up the Arduino, Raspberry Pi, and NVIDIA Jetson success stories.

Certainly, credit for three successful cases mentioned above goes foremost to the dedication and ingenuity of the instructors, second to the departmental support staff, and third to the flexibility and convenience of the technology involved. For in-person instruction on campus in normal times, specialized electronics-related lab activities have understandably been solely the domain and responsibility of specific departments. In the wholly different context of a crisis like the pandemic, however, we should consider what might be possible for making these sorts of opportunities available more broadly to many instructors, especially those who are less familiar with such technologies.

Likewise, an argument can reasonably be made for handling the supply chain management for these devices more strategically at the enterprise level rather than leaving it as a desperate scramble for individual departments. In crisis response mode, many high education institutions found it generally expedient if not essential to expand the reach of their central services as a lifeline to departmental operations, whether in the case of licensing videoconferencing and collaboration tools or by folding local IT staff into a central support matrix. A similar necessity arises when considering the scaling up of the lab and hands-on activity success. An economy of scale might be achieved where expertise that would otherwise be siloed in local departments could be shared widely. While the specific disciplines in the three use cases described in this paper involved Physics, Design, and Engineering courses, the instructional applicability of the technologies spans across many other disciplines including architecture, art practice, business schools, environmental and even biological sciences [14].

Given the existing adoption and the potential for broader deployment, central academic computing organizations could begin the exploration of service offerings by developing in-house expertise

Table 1: Overview of device families and characteristics

	Arduino	Raspberry Pi	NVIDIA Jetson
<i>Types & Models</i>	Compatible hardware spans > 80 models in all shapes and sizes categorized as Entry Level, Enhanced Features, IoT, Industrial, etc.	Roughly a dozen models across five generations.	Currently, five boards in the Jetson family: TK1, TX1, TX2, Xavier, Nano
<i>Hardware Characteristics</i>	Microcontroller AVR ATmega Typical Memory Size: 32k - 256k	System on a Chip (SoC) architecture Quad-core ARM Cortex CPU Broadcom GPU Typical Memory Size: 4GB	System on a Chip (SoC) architecture Quad-core ARM Cortex CPU NVIDIA GPU Typical Memory Size: 4GB
<i>Operating System</i>	None	Raspberry Pi OS (Debian Linux), Ubuntu Linux MATE, Windows 10 IoT Core, RISC OS, Free BSD, OpenBSD, NetBSD, etc.	Linux for Tegra (Ubuntu Linux), Redhawk RTOS, QNX
<i>Development Environments</i>	Arduino IDE (for Windows, macOS, and Linux) Arduino Create (Chromebook)	Mu, IDLE, Geany and Thonny (for Python) and many more. Various SDK options for ARM cross-compilation	NVIDIA JetPack tool bundle integrates Eclipse, CUDA and OpenCV support.
<i>Educational Support</i>	Arduino AG (arduino.cc)	Raspberry Pi Foundation	NVIDIA Higher Education & Research Developer Resources
<i>Cost</i>	\$10-\$25 (US)	\$35-\$75 (US)	\$59-\$1100 (US)

among staff with one or more of the device families described in the examples. All three platforms are made especially accessible by the wealth of training, documentation, user communities, and online suppliers available. From a technology perspective, these platforms share fundamental architectural and operational characteristics with larger computing systems already being supported. When compared in terms of power and storage capacity to the full range of laptop, desktop, and workstations traditionally used in academic settings, these microcontrollers and microprocessor devices may initially appear rather modest in capability. However, as examples of potentially dispersed connection points for capturing input from diverse sensor inputs out in the real world, they represent revolutionary progress in enabling far-flung data acquisition and processing well outside the traditional boundaries of campus facilities [15]. Moreover, as examples of different kinds of open source and open hardware development efforts designed for explorative learning, these technologies are intended to be affordable and easily supported [16]. Happily, most aspects of these computational systems and their community resources are made available under open source, open hardware, and open content licensing models.

5 CONCLUSION

This paper has been intended mainly as a prompt for considering ways in which academic computing services might play a role in supporting new kinds of remote educational activities made possible by low cost microcontroller and microprocessor devices. The three case studies demonstrate the individual ingenuity and resilience of the instructors involved as well as the support of their local departments. To scale up such efforts would require an institutional effort to invest in provisioning, consultation, training, and service support. In times of crisis, the curriculum in many fields could benefit from expanding to include the teaching of skills and in deploying the appropriate hardware and software for solutions out in the field and hands on activities at the edge.

Even from just the three examples of how several courses adapted these device-based activities, the potential for greatly enhancing remote instruction can be seen. The combination of ingenuity and local departmental support have enabled these inspiring successes. At the enterprise level, supporting these teaching and learning activities involving microcontroller and microprocessors computing would draw upon traditional strengths in strategic sourcing, training, and consultation services while also aligning the enterprise

with the computing trends they represent [17]. Above all, these remote learning activities could provide great benefits in sustaining the academic mission in times of crisis. For academic technology services in higher education to keep up with the new context of risk, the support service and processes we employ will need ever greater focus on business continuity and resilience for the core teaching and learning mission. Being alert and responsive to emerging solutions can be one means to finding a way forward.

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