

Remote Hub Lab – RHL: Broadly Accessible Technologies for Education and Telehealth

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Abstract. The start of the current decade has been marked by challenges arising from service disruptions associated with the spread of COVID-19, impacting the education and healthcare sectors particularly deeply. Ongoing efforts to virtualize data acquisition in related scientific disciplines have often neglected to design user-facing technologies which adequately scale for large audiences, effectively depriving them from resource-limited individuals. The lack of physical hardware necessary to implement specific features remotely further complicates such efforts. To improve access for all individuals and combat widespread distribution inequities in medical and educational institutions, the Remote Hub Lab (RHL) and its core research projects are designed to introduce new, scalable technologies targeted towards telehealth and higher learning.

Keywords: Remote Labs, Wound care, 3D scanning, Telehealth, ostomy care, Digital Design, Field Programmable Gate Arrays FPGA, Software Defined Radio SDR, RHL-Butterfly, Equitable Access, Engineering Education.

1 Introduction

The ability of technologies to enable communication virtually through 19th and 20th century novelties ranging from radio to the Internet have long facilitated the rise of an increasingly interconnected global society which gathers and shares information over long distances. Deployment of solutions for emerging issues has accelerated, benefiting the scientific community's progress at large. With the onset of a worldwide coronavirus pandemic in 2019, individuals formerly relying on direct interactions pivoted towards remote alternatives, typically aided by the aforementioned technology. However, remote engineering's capacity to fully replace in-person communication has been hindered by the absence of robust environments in various fields, including education and clinical health. Student satisfaction with remote learning, for example, has often been determined to be lower in comparison to traditional learning, with researchers citing stress [1], lack of motivation [2], social isolation [3], and time management [4] as possible issues. Disparities in satisfaction across genders [5], disciplines [6][7], and financial statuses [8] have further raised questions over the potential for biases introduced by remote technology and its implementation.

Telemedicine, and its proliferation in the wake of coronavirus, has also been limited due to patients' concerns of cost [9], privacy [9][10], and diagnosis bias, all of which may impact perceptions of trust. With respect to diagnosis bias, prior research has confirmed that existing commercially-available medical devices, such as the pulse oximeter, are indeed more prone to misdiagnosing individuals with darker complexions [11-13], proving that such concerns are not unfounded.

As demand for remote engineering platforms is only expected to increase with the growth of stay-at-home work policies and the possibility of future circumstances akin to the pandemic, there is a critical need to address the ongoing issues with remote engineering. The Remote Hub Lab (RHLab or RHL) team is dedicated towards this purpose, with existing projects geared towards remotely accessible hardware and telemedicine. In the following sections, each project is discussed, with expected contributions and a high-level overview of internal details.

2 RELIA

2.1 Overview

RELIA¹ (stands for Remote Engineering Laboratories for Inclusive Access): A New Generation of Broadly Accessible Remote Engineering Laboratories, is a collaboration between RHLab and LabsLand². The project aims to support underprivileged educational institutions and their associated communities by introducing an interactive computing and wireless communication laboratory based on field-programmable gate arrays (FPGAs) and software-defined radio (SDR) platforms. Because of the COVID-19 crisis, hands-on engineering courses frequently offered at schools and universities have been forced to evolve towards off-campus options, often at the expense of physical training necessary for real-world learning. By taking advantage of advances in cloud computing, educators of embedded computing and wireless communications courses using RELIA will be able to deliver a fully-fledged alternative to in-person coursework for students that is both cost-effective and equitable.

Labs are expected to be disseminated over a highly modular repository and partnerships between schools will be encouraged to improve course materials. An educational remote laboratory (ERL) enables students to access real equipment located in their institution, as if they were in a hands-on session, using a standard web-browser. Such laboratories are typically hosted in universities or research centers [14]. Two or more institutions should be able to share different equipment to reduce costs, as individual equipment is expected to only be used within a specific given timeframe. A traditional software-defined radio laboratory conducted in-person would entail a separate receiver and transmitter (in addition to associated coaxial cables, connectors, antennae, etc.) which, through software (e.g. LabVIEW, GNU Radio Companion, MATLAB+Simulink), are able to communicate using radio-frequency (RF) signals processed at the receiver end (see Fig. 1). RF interference may occur if multiple active setups are located in proximity to one another without significant isolation.

¹ RELIA is funded by the National Science Foundation, award # 2141798

² <https://LabsLand.com>

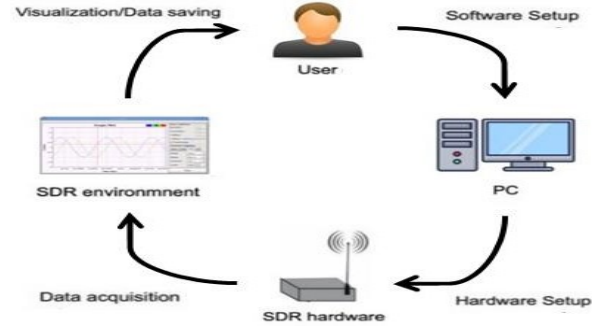


Fig. 1. The general configuration for a software-defined radio (SDR) laboratory

The SDR package utilized for this project is GNU Radio Companion, a graphical environment for designing radio-based devices which enables users to construct flowgraphs by adding and connecting on-screen blocks. The output of a flowgraph (a GRC file) is converted to a Python script at compile time.

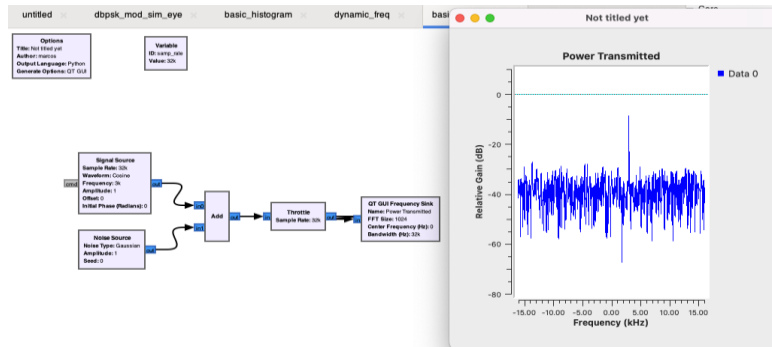


Fig. 2. (left) The GNU Radio Companion flowgraph for a sine wave transmitter, consisting of four individual blocks (right) The QT-based widget that displays the signal

2.3 Design

Software. The modular software package consists of a web server with a set of services that provide the user interface (offering full interaction with GNU Radio applications through input widgets and output graphical sinks included in the package) and setups which each consist of two Raspberry PIs (corresponding to receiver and transmitter). As shown in Fig. 2 for an example sine wave transmitter, widgets are represented as linkable blocks in a flowgraph, with the last block corresponding to a QT GUI frequency sink. All communication occurs over HTTP and various web sockets with the server; a scheduler manages the assignments of setups with available sessions. When a student is assigned a setup, two GNU Radio configurations are required for proper Raspberry Pi loading. A user will first submit a GRC file to RELIA, which will be compiled following widget examination using the GNU Radio Companion Compiler

(GRCC). The product is then executed, with generated data being stored in a REDIS database (for future data streaming on the web interface).

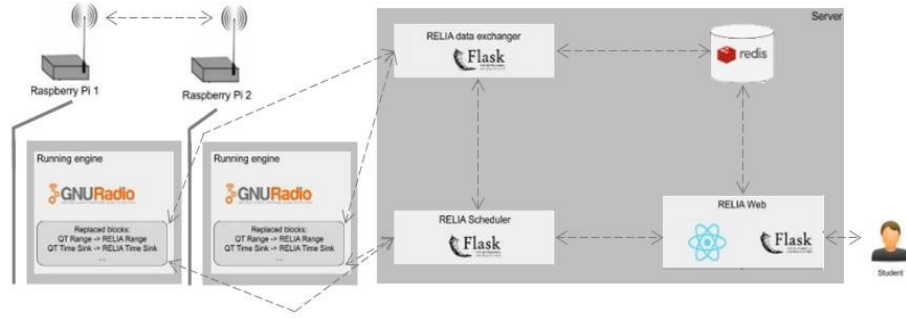


Fig. 3. RELIA software architecture

Hardware. Adam-PLUTO was selected, due to its large existing user base, technical specifications (e.g. relatively high signal-to-noise ratio) and flexibility (e.g. in operation and rate). The Raspberry Pi controls the Adam-PLUTO over high-speed data transfer (facilitated by shared Python language). As mentioned previously, RF interference may occur; the proposed solution is to isolate every transmitter-receiver pair in a Faraday cage consisting of a nickel and copper sheet shield. To test this solution, a sequence of 100,000 ASCII characters was transmitted using binary phase-shift keying (BPSK) modulation. The packet reception ratio (PRR) was used as a metric for transmission efficiency. When no Faraday cage was used for two adjacent receiver-transmitter pairs, approximately 15% of all packages were lost in transmission over a distance of 0.1 m, with PRR increasing to 96% over a distance of 1 m. With one Faraday cage, PRR increased to approximately 98% over distances of both 0.1 m and 1 m, while with two Faraday cages, PRR increased to well over 99%.

The RELIA project is open-source, with repository links expected to be available on the Remote Hub Lab's official website. When coupled with the WebLab-Deusto software (made available by collaborator LabsLand), it is anticipated that multiple institutions which are already part of the LabsLand network will be able to adopt the laboratory using existing functionalities provided (e.g. integration with learning management systems such as Moodle, Canvas, Sakai, etc.).

3 Wound-Mate Telehealth System

3.1 Overview

In the aftermath of the pandemic, healthcare providers have suffered short staffing, leaving the existing healthcare professionals spread thin. Telehealth can help improve the efficiency of providers, thus increasing the number of patients seen, and the quality of resources available to a patient. Our lab is addressing the need in wound care through a pilot project called Osto-mate³ to promote the quality of ostomy care

³ Osto-mate project is funded by UW Research Royalty Funds, and by a NSF I-Corp grant.

available to ostomates through telehealth practice. Ostomates are patients who undergo ostomy surgery, in which their gastrointestinal or urinary tract is opened and diverted out of an opening in the abdomen. Patients must maintain the wound and the skin around it, using an ostomy wafer, ostomy bag, and paraphernalia. The preparation of the wafer can be time-consuming and imprecise, a wafer cut too loosely will expose the skin to feces, leading to skin erosion, infection, and leakage. A wafer cut too tightly can cause trauma to the stoma and result in bleeding and stoma suffocation [15, 16]. To address this issue, the lab is developing the system in Fig. 4 along with various other psychological and educational resources that ostomy patients have identified as a key need post-surgery.

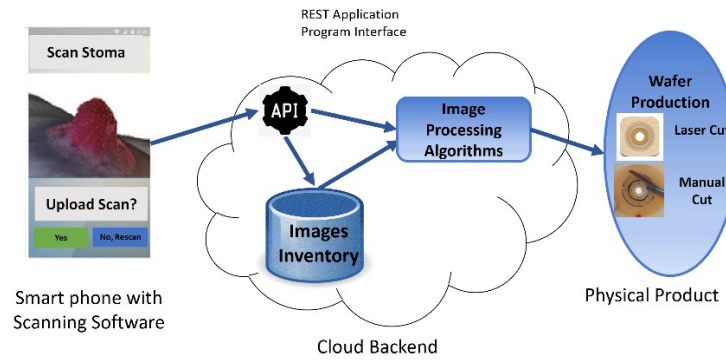


Fig. 4. Wound-Mate's ostomy wound management system architecture.

3.2 Design

The system in Fig. 4 depicts the process of obtaining a customized wafer. In the first section, a scanning device, which can be generalized to newer smartphones with 3D imaging technology, obtains a 3D image of the ostomy site. A 3D image is required because the intestinal spout may protrude and occlude the base on the stoma from a single overhead image. In the second section, image processing algorithms are used to generate the outline of the stoma from the 3D image. Finally, in the third section, the outline generated in the second section will be machined into ostomy patients' wafers or hand-cut by an able body such as a patient's ostomy supply distributor, family and friends, or home health nurse.

Hardware. The system development uses iPhone 12 Pro smartphone with the TrueDepth 3D imaging technology [17]. The imaging technology of the iPhone 12 Pro can generate simple 3D images with an accuracy better than 2 mm [18]. In addition to making the system accessible, using smartphones allows us to develop psychological and educational resources needed by the ostomy community. We have identified such needs by interviewing over 100 ostomy patients and nurses. Post-surgery, patients are assisted by an ostomy nurse before being discharged, but they are under the influence of anesthesia and suffering from the trauma of the surgery, especially if they underwent an emergency ostomy surgery, so they struggle to remember all the information given to them. In some cases, ostomy patients are only seen by the ostomy nurse on the day

of discharge. Thus, in general, many patients rely on a family member or friend to search for care information and assist them in maintaining the ostomy site. In addition, during the two to three months after surgery, the ostomy patients are the most grief-stricken and overwhelmed. By providing ostomy patients with additional resources, we hope to improve their health-related quality of life post-surgery as quickly as possible.

Software. The iPhone’s TrueDepth camera system was tested using the open-source InfiniTAM_ios application [19]. The InfiniTAM_ios application interfaces the InfiniTAM framework [20], which stitches 3D images to reconstruct a model, with the TrueDepth camera system. The application allows for the development of colorless stereolithography (STL) models in real-time. The TrueDepth camera system hardware appears to generate 3D images of simple objects well, but software improvements are needed for side-angle scanning and improved tessellation of objects with sharp edges or geometrically complex surfaces [18].

Our team’s approach to making telehealth for wound care more accessible starts with ostomy patients, as wound care can be hard to manage in any environment, especially in the ostomy environment. The lack of specialized care for ostomy patients is widely observed within the community, and the lack of education seen in patients is detrimental as patients are coming out of the hospital without knowing how to care for themselves properly and are unsure of their medical needs. Patients in rural areas or smaller communities have an even tougher time accessing healthcare as their resources are limited or nonexistent. In many cases, these patients wait until their health status is worsened, relying on the limited medical knowledge in their area for emergencies, which are improperly addressed, making the situation worse.

By generating accurate scans of the ostomy site, we allow medical providers to have a clear picture of the patient’s wound so they can provide patients with an overall health check from the comfort of their homes. The doctors and nurses can also flag any issues that might require future examination and request of the patient to come to the hospital to address them. Thus, near-term future work will focus on improving the accuracy of the capture 3D images by building upon InfiniTAM’s framework and the interface with iPhones to improve side-angle scanning and tessellation. Additionally, the scanning application will generate colored models, which would allow for better model analysis and, eventually, diagnosis. With improved 3D reconstruction, we will experiment with 3D wound segmentation to generate the optimal stoma contour to be cut into the wafer. We must note that diagnosis is a long-term goal because the Federal Drug Administration’s regulation restricts current usage parameters of the iOS application to record-keeping, so we must explore safe, viable ways in which the telehealth application can be used for diagnosis.

Other exploration in the application development includes UI/UX research in creating a platform, with input from current ostomy patients, that is intuitive and easy to navigate. As seen in [21], while telehealth has increased significantly during the COVID-19 pandemic, older patients have had less success or interest in telehealth due to disabilities, low access to technology, capability of using newer technologies, and other environmental issues. Our future work will focus on improving wound care accessibility through telehealth and remotely accessible technologies.

4 RHL-Butterfly

4.1 Overview

The RHL-Butterfly⁴ [22] is a scalable, IoT-based virtual breadboard delivering customizable digital logic circuit designs for FPGAs and microcontrollers. Our solution takes into consideration real-time embedded systems throughout the breadboard prototyping experience and uses physical hardware to capture the circuit responses. Our open-source virtual breadboard solution is incorporated into a platform accessible by anyone to focus on bringing equitable virtual laboratory solutions to many different engineering curriculums around the world. The COVID-19 pandemic sparked an increase in the research of educational technologies for engineering curriculums and had popularized virtual laboratory equipment and implementation [23][24]. Additional studies have shown that engineering curricula using virtual laboratory equipment can lead to better learning outcomes in certain aspects [14][25], bringing potential viability for virtual laboratories even in a post-pandemic world. A rudimentary iteration of a virtual breadboard delivered promising educational experiences [26], providing motivation for the continued expansion and scalability of the RHLab remote breadboard platform by bringing additional supported integrated digital circuits and support for more target hardware.

4.2 Design

RHL-Butterfly is composed of three separate components, as shown in Fig. 5: the client frontend, constructed using HTML and JavaScript, the interface network, consisting of a Raspberry Pi 4 and a Raspberry Pico, and the target hardware, whose responses are captured via a livestream that feeds back to the user through that frontend interface.

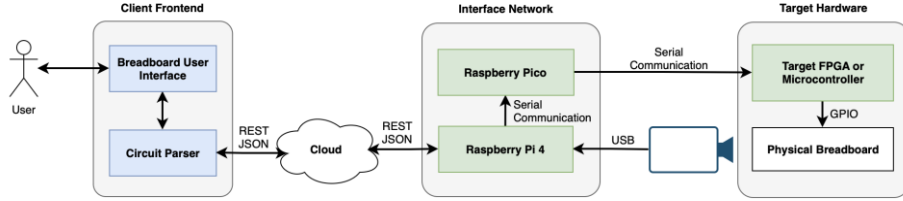


Fig. 5. The top-level block diagram of the RHL-Butterfly, consisting of a frontend user interface, interface network hardware, and the target hardware for circuit responses.

The client frontend uses the VISIR breadboard library to construct its Graphic User Interface (GUI) [27], allowing users freely draw wires around the breadboard. A JavaScript circuit parser continuously maps the breadboard and computes the breadboard state. This circuit parser also handles any circuit errors it sees and notifies the users with hints to correct their breadboard designs.

⁴ RHL-Butterfly is funded by Intel Corporation

Once the user is satisfied with their constructed design, they submit their breadboard for synthesis, to which the circuit parser then maps the drawn wires and outputs the information to a JSON equivalent breadboard, which is captured by a local Raspberry Pi 4. Because information on the breadboard design is passed to the Raspberry Pico through serial communication, the JSON equivalent breadboard information is then encoded into a custom string protocol, allowing for straightforward information transfer. The Raspberry Pico parses the strings, computes the digital logic, and then instructs the target hardware to display the corresponding GPIO logic. A local camera livestreams the responses of the target hardware to the user on the GUI using the open-source WILSP technology to significantly minimize livestream delay of the hardware responses [28], allowing for an immersive virtual laboratory experience.

RHL-Butterfly delivers integrated circuit support for digital logic gates, such as AND, NOT, and OR gates. Future iterations of the virtual breadboard platform will expand the custom string serial communication protocol to encompass additional analog integrated circuits, such as Operational Amplifiers, Analog-to-Digital Converters, etc. An increase in supported virtual breadboard hardware provides opportunities for students to explore a wider range of embedded system designs, thereby strengthening virtualized engineering curriculums.

5 RHL-BEADLE

5.1 Overview

The RHL-BEADLE⁵ project (stands for Bringing Equitable Access to Digital Logic Education) began as a way for students to remotely access learning digital design and to interact with Field Programmable Gate Arrays (FPGA). One weakness in electrical engineering education RHL identified during the COVID-19 pandemic was how to ensure expensive and sparse laboratory equipment is provided to learners [14]. More to the fact, it has been identified as early as 1929 that providing laboratory equipment in education settings proved to create an imbalance of accessible pedagogy for students [29]. To provide equitable and accessible opportunities, the lab capitalized on an opportunity to modernize electrical and computer engineering. This project aims to promote inclusive learning for learners regardless of their physical location and access to hardware. Accordingly, the hardware used for this project consists of remotely accessible FPGAs of Intel's DE1-SoC boards. When the project experiences high traffic of users, if no FPGAs are available in our local lab in Seattle, alternate boards from other laboratories [30] are utilized. RHL-BEADLE also provides integrated breadboard support with the RHL-Butterfly virtual breadboard platform to further enhance digital logic education. In addition to synthesizing FPGA designs on the DE1-SoC hardware servers in the RHLab, this breadboard integration to the RHL-BEADLE curriculum allows students to design similar fundamental digital logic circuits using integrated circuit chips and simulating these designed circuits on FPGA platforms. In addition, utilizing breadboard prototyping experiences to the GPIO of the FPGAs enhances

⁵ RHL-BEADLE is funded by Intel Corporation

student creativity to the overall system design and architecture of embedded systems and digital circuitry.

5.2 Curriculum

When considering curriculum, it is important to note that there are a variety of factors that play into learning including how learning is approached and presented to individuals [31]. As remote labs have developed in popularity in the modernization of pedagogy, skeptics have doubted the effectiveness of remote learning specifically when it concerns collaboration and hands-on experience [32], while supporters argue there is much to gain particularly when considering inclusion and individual learning styles [33]. When creating curriculum for lab activities it has been crucial in our development to take both concerns and praises into account. In addressing historical downfalls to remote learning one important aspect has been to create space for students to communicate ideas with their peers. While a successful curriculum can be designed for individual learning, a consistent, effective curriculum needs to provide opportunity for knowledge and interpretation to be shared amongst a community. In respect to capitalizing on the perks of remote learning, creating a variety of interfaces for users to choose to interact with our curriculum has been essential. This is most prevalent when acknowledging the motivation of this project is to provide the ability to use electrical engineering equipment with limited barriers with respect to an individual's socioeconomic status. Moreover, inclusivity and equity have been a cornerstone to the labs development as the curriculum is refined [34]. This is seen from a commitment to empower learners to utilize the curriculum effectively with limited to no prior experience or professional guidance. The project also sees the potential to provide equity from a financial outlook particularly with cutting the costs of purchasing electrical equipment for individual students. The digital divide can thus be addressed by providing practical ways in addressing inequity of access to resources and information. While the RHL-BEADLE curriculum provides a current focus on digital design and FPGAs, RHLab has expanded its hardware to include 36 Intel DE1-SoC FPGAs, four Arduino Robots, eight Arduino Uno AVX boards. Additionally, a remote lab of eight Texas Instruments ARM microcontroller development boards is being developed (Fig. 6).

This hardware is connected to similar labs at other universities through LabsLand's global network of remote labs [35], which provide opportunities for increased participation to the RHLab laboratory environment beyond digital logic design. RHL-BEADLE continues to drive the motivation of bringing equitable access to engineering education, with planned support for K-12 STEM curriculum and robotic competitions. The focus of the project has shifted towards providing services to classrooms and the public. This includes testing and monitoring the effectiveness of learning in university classrooms, creating unique labs for specific academic experience levels, and promoting this resource to a wide array of populations. The project looks toward finding upper limits of educational experiences with the current model of remotely accessible hardware.

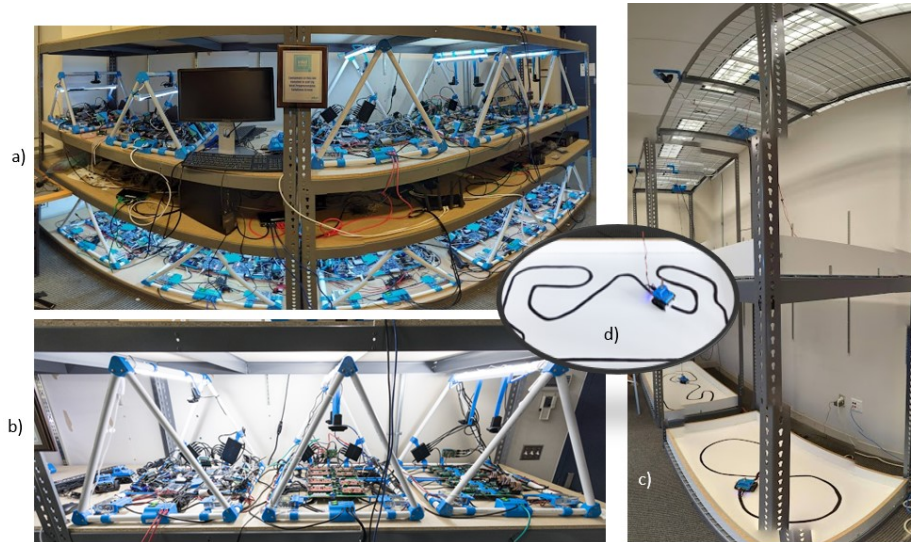


Fig. 6. The RHLab's hardware. a) A picture of the remote lab structures that include 36 FPGAs, 8 Arduino UNOs, and 8 Texas Instrument ARM microcontrollers. b) LabsLand's triangular shaped structures with FPGA boards (left), Texas Instrument boards (middle), and Arduino Uno boards (right). c) Two structures, each has 2 Arduino robots (top and bottom levels). d) A close-up of an Arduino robot following a path finding algorithm.

6 Conclusion

The projects discussed in this paper collectively serve as a summary of the Remote Hub Lab's mission and a guide for future developments which the lab aims to accomplish in upcoming years. As each project progresses with respect to demonstration, implementation, and/or commercialization, it is expected that more individuals will have improved access to invaluable knowledge, whether it be connected to wireless communication skills, wiring, or their own physical well-being. Although the pandemic pandemic fueled a growing divide in terms of accessibility within higher education and the medical community, it has also arguably awakened a greater sense of what is missing amidst the constant bustle of technological innovation and cultivated a shared interest in improving the state of remote technology for future generations.

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