You have a Science Laboratory in the Palm of Your Hand

Our world is changing rapidly. During my college days, computers were a marvel. My first computer was a device that had 65KB of RAM (random access memory, the working memory of the device), and memory was expensive (this fact dates me). Note the unit is kilobytes – 1000 bytes. The Apollo 11 space craft's guidance computer had 4KB of RAM[1]. Many of your "smart" devices like doorbells, refrigerators, and toasters have more RAM than that Apollo computer. My not so high-end smartphone has 4GB of RAM (note the unit here is gigabytes – 1,000,000,000 bytes). This is just the memory component.

Your smartphone, in addition to acting as a communication device, is full of different sensors. It can pinpoint your location. It is a computer. It is a fitness device, i.e., it can tell you the pace you are walking or running. It is a recorder. It is a gaming device. It is an entertainment system. The list goes on. So, why not tap into these sensors and make our smartphone a traveling science laboratory. And, given the changes we are seeing, i.e., more virtual learning, more discovery learning, we have essentially given anyone with a smartphone more science gathering and experimental capacity than that provided to the astronauts that landed on the moon!

The key is understanding what you have in the palm of your hand and the ability to access it. Some very creative and knowledgeable people have stepped up to help. (And, if you are not careful and allow those creative students to explore and code, they may be able to tap into the device even more and develop applications to monitor our surroundings and expand the capabilities.) Remember, when some of us would say there is an App for that, guess what? If there isn't one now, there is one likely soon. Here are some applications that those of us who are instructors, parents, and plain science lovers can tap into to conduct some really cool science.

Sound. Your phone can be a pitch pipe, a frequency generator, a decibel meter (measure the intensity of the sound) and a spectrum analyzer. Intensity monitoring can come in handy in loud workplaces as it can help individuals identify when hearing protection is needed. The spectrum analyzers are also handy if you are trying to locate a particular "hum." But, for science experiments, these are also tools that can be utilized for observing the doppler effect (see Science on Stage[2] and Phyphox[3] for these types of experiments). The Phypox application utilizes the sound sensing capabilities for the measurement of the speed of sound and as a sound timer that can be used for several kinematic experiments, like measuring the acceleration due to gravity or measuring the time it takes an object to move from one location to another. The Phypox application has a sonar mode.

Light and Optics. The smartphone, with a bit of assistance, can become a microscope or a hologram projector. The Pacific Northwest National Laboratories has instructions for how to print your own microscope for your phone or tablet[4] (if you have access to a 3D printer), but there are other relatively

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[1] https://www.sciencefocus.com/space/what-tech-would-the-apollo-11-mission-have-today/#:~:text=The%20Apollo%20Guidance%20Computer%20had,times%20those%20achievable%20in%201969.

[2] Science on Stage - The European Platform for Science Teachers - https://www.science-on-stage.eu/page/display/5/28/1290/istage-2-smartphones-in-science-teaching

[3] Phyphox – Physical Phone Experiments - https://phyphox.org/

[4] https://availabletechnologies.pnnl.gov/technology.asp?id=393

inexpensive microscope adapters that can be found on the internet. The hologram projector[5] can be made with materials from a blister pack. The *Science on Stage* has an experiment that describes how to measure distances between stars, locations on campus, and heights of objects, by using a protractor and measurement application. (If you are doing astronomy, there are several excellent star gazing applications. These applications even provide alerts informing the users about upcoming astronomical events.)

Other Physics. An application for Android and iOS, SensorKinetics, provides access to the phone's accelerometer, gyroscope and magnetometer, light sensor, and pressure sensor. The Science on Stage manual provides an experiment that will allow students to measure the Earth's Magnetic Field and use the accelerometer for a variety of experiments. The NASA Space Science Education Consortium has put together an "Experimenter's Guide to Smartphone Sensors."[6] The guide is 209 pages of background information, suggested applications, and experiments that can be used in the classroom or at home.

While instructors and educators might be experiencing a variety of difficulties. It is likely that each of us and our students will be able to get access to a smartphone or a tablet. Thus, we now have the capability of putting scientific equipment into their hands, as long as we can get an application onto the device.

[5] Hologram with Smart Phone or Tablet - YouTube https://youtu.be/VRljGNLyMYY and YouTube to see Hologram https://www.youtube.com/watch?v=Y60mfBvXCj8. Template https://www.bealsscience.com/post/2016/02/15/3d-hologram-projector-for-you-phone-or-tablet

[6] https://spacemath.gsfc.nasa.gov/Sensor/SensorsBook.pdf