# TURN YOUR SMARTPHONE Into a SCIENCE LABORATORY

*Five challenges that use mobile devices to collect and analyze data in physics*

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Mobile devices have become a popular form of education technology, but little attention has been paid to the use of their sensors for data collection and analysis. This article describes some of the benefits of using mobile devices this way and presents five challenges to help students overcome common misconceptions about force and motion. We've used these challenges—and the apps we created to go along with them—in our physics classes but have also found them useful in environmental science, chemistry, and biology classes as well.

## Using mobile devices in science

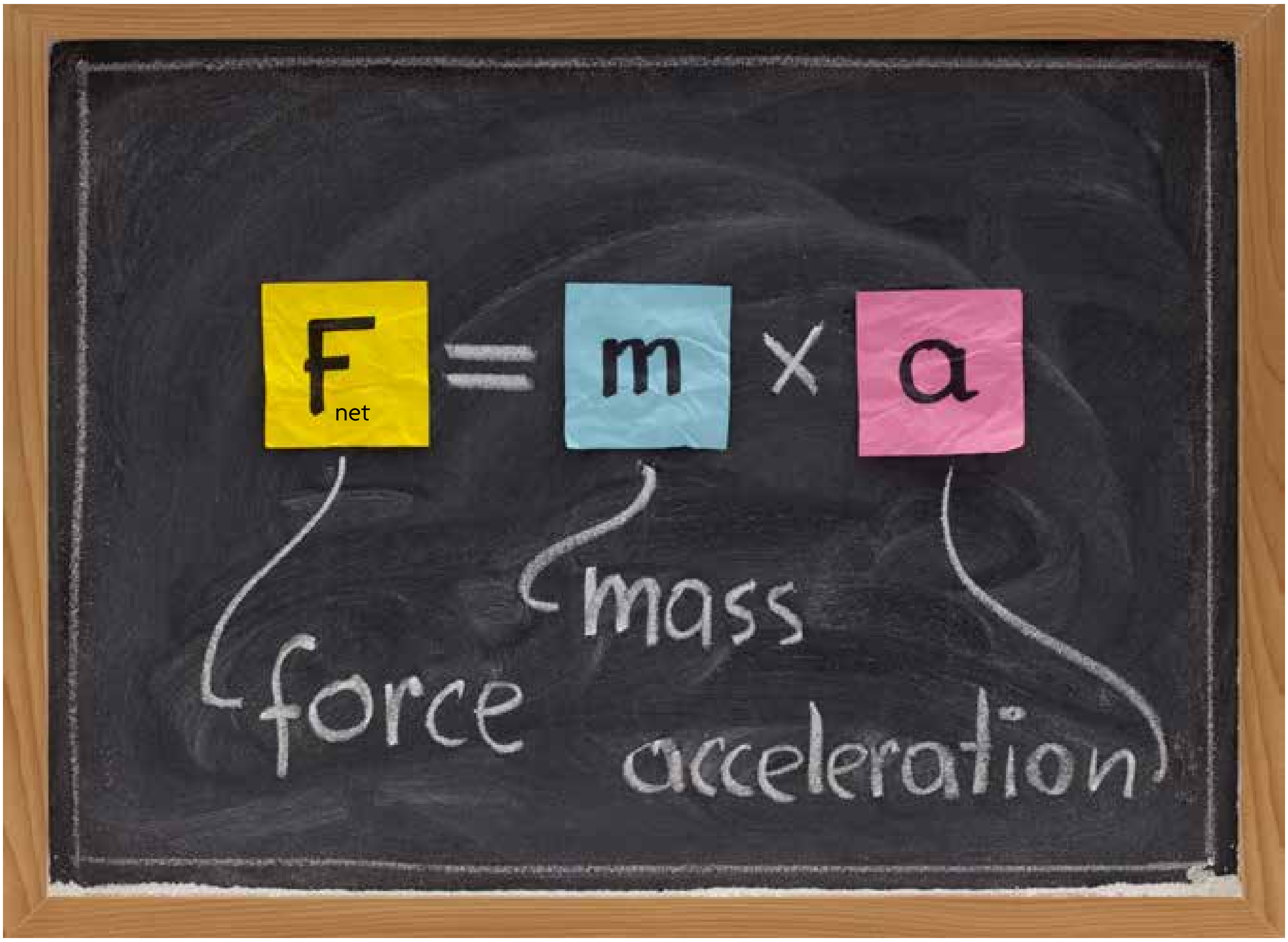
Though U.S. science classrooms have used smartphones for data collection (Huffling et al. 2014; Heilbronner 2014), the international education community appears to have used them longer, having produced several lab ideas relevant for high school physics teachers in the United States (Kuhn and Vogt 2013; Barrera-Garrido 2015; Monteiro et al. 2014; Science on Stage Europe 2014; González et al. 2015). Many of the apps involved use a smartphone's accelerometer, a sensor particularly well suited for teaching concepts of force and motion and cause and effect (Figure 1, p. 34; Monteiro, Cabeza, and Marti 2014; Tornaría, Monteiro, and Marti 2014; Vieyra and Vieyra 2014). The accelerometer is a micro force meter using small pieces of silicon that move in response to changes in orientation (see box). Students can use apps that use this sensor to measure linear acceleration and compare different types of motion, including constant velocity, linear acceleration, and centripetal acceleration. Knowing the mass of the mobile device allows them to measure its net force using Newton's second law, $F_{net} = ma$, as well.

Research shows that students struggle conceptually with the relationship between force and motion and especially with the concept of centripetal force as inward directed. Research by Hestenes, Swackhamer, and Wells (1992) on the Force Concept Inventory (FCI) shows that students typically gain only 24% to 42% on the FCI after traditional instruction involving lecture and cookbook labs. This suggests a need for more engaging instructional strategies.

Mobile devices allow students to graphically model physical relationships (Arizona State University 2015) and to collect data outside the classroom, such as in the field or at home, so students can better see and understand science concepts in contextualized, relevant environments and improve their skills in science and engineering practices as described in the *Next Generation Science Standards* (NGSS Lead States 2013) (see box, p. 38; ISTE 2007). Data collected in environments such as these are typically big, "messy," and more realistic than that collected in the lab and thus present increased opportunities for learning and engagement.

### The accelerometer, explained.

Mobile devices have several internal sensors that help them perform everyday functions such as rotating their screens or adjusting for brightness. One such sensor is the accelerometer, made of small pieces of silicon that move in response to changes in orientation. Many apps use the data this sensor collects: Some read the strength of gravity for a stationary object as 9.8 m/s/s vertically (this is the relativistic acceleration, which can be confusing for students studying Newtonian mechanics), while others filter out this value to give a reading of 0 m/s/s, or 1g in g-forces. (Note: A *g-force* is the ratio of normal force to gravitational force; *normal force* is defined as the force of a surface pressing into the object touching it, perpendicular to the surface.) The five challenges described in this article use data gathered by an accelerometer. See "On the web" for a video that explains this sensor in more depth.




## How to use mobile devices inside and outside the classroom

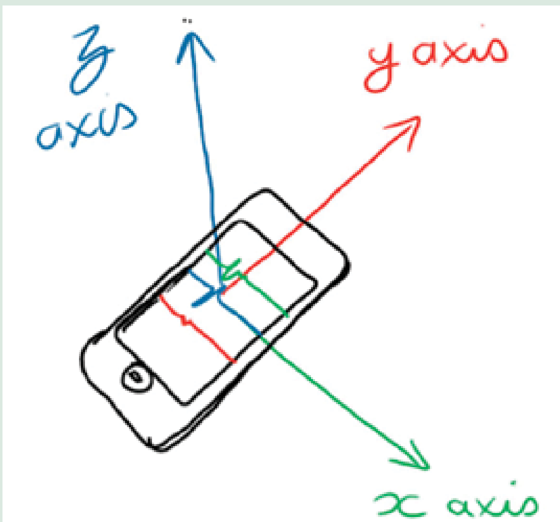
Below are challenges we have used with students in regular introductory algebra-based physics courses around the world. Note that many schools still restrict the use of personal mobile devices in the classroom, so consult school administrators before starting. Discuss with students mobile device etiquette, including, if appropriate, that devices be screen-down during teacher-directed activities or class discussions. Also remember that any new technology in the classroom takes time to learn. Once learned, however, mobile devices can speed up data collection. Allow students time to explore what data their mobile devices can collect and what manipulations change the data collected.

Students should investigate where the *x, y,* and *z* planes are on their devices (Figure 1) and how they are represented graphically. Students must understand what the device is measuring, and, if appropriate, how the internal sensors work (see box, p. 33).

Students complete the five challenges presented on the following pages. Although nearly any Android or iOS app with

**FIGURE 1**

***X, Y,* and *Z* axes.**

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graphing capabilities can be used for the following activities, the "Physics Toolbox" app was created to accompany them to allow students to do science within and beyond classroom walls. Lesson plans, challenge worksheets, and suggested apps are available online (see "On the web").

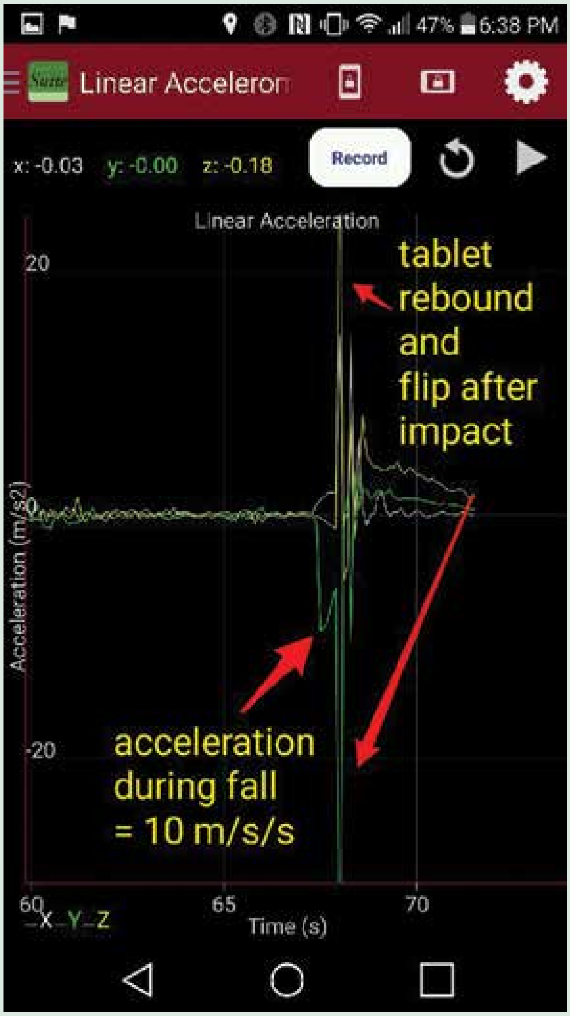
### Challenge #1: Acceleration due to gravity in the home

Although the concepts of velocity and acceleration should be first developed through in-class lab experiences, students can also measure their phone's acceleration due to gravity in their own homes. Students must work with teachers and parents to determine how to do this in a way that is safe for them and their mobile devices. Most elect to measure acceleration when the phone is dropped from eye level onto a soft couch or bed. This task presents students with lots of intriguing questions, such as, "How should the mobile device be held upon dropping?" and "Which axis is measuring acceleration due to gravity?"

Because the fall time is relatively short, students are challenged to find the relevant data corresponding to the fall and must pinch to zoom in to see the acceleration value (Figure 2). This acceleration, with a value of about 9.8 m/s/s, can usually be seen immediately before the mobile device's much greater impact force with the sofa or bed. This leads to other questions, such as how to best determine the acceleration due to gravity when each mobile device gives slightly different results, or why some students get positive accelerations, while others get negative values. Students can also compare accelerations for devices of significantly different masses, such as a small smartphone and a large tablet, helping them to connect to *NGSS* standard HS-PS2 and to determine both the cause of acceleration and which variables influence (or do not influence) it (see box, p. 38).

**FIGURE 2**

**Acceleration during free fall.**

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### Challenge #2: Net force and motion in an elevator

Traditional "elevator" problems in physics require students to consider forces on a person or object while accelerating up or down. Mobile devices simplify the understanding of these problems, especially when the accelerometer is set to read g-forces instead of linear acceleration. A major student misconception is that an elevator moving upward—even at constant velocity—must have a net upward force acting upon it. To confront this misconception, students can use their mobile devices to observe changes in linear acceleration and g-force as they go up a level in an elevator. (To more effectively elicit this misconception, ask students to predict what they think g-force graphs will look like for an elevator throughout its travel as it goes up from one floor and comes to rest on the next.)

Although students feel an initial increase in acceleration during the start of the ascent and observe a spike in g-force (Figure 3, p. 36), the "middle" portion of the ride before the elevator begins to slow shows a constant g-force equal to 1. A graph of acceleration and g-force while moving upward at constant velocity looks identical to one produced by an elevator that is not moving at all. After collecting the data, students can compare their predictions with the actual graph and determine why there might be discrepancies between the two.

More advanced students can use Newton's second law of motion ($F_{net}=ma$) and the mass of their mobile device to draw quantitative force diagrams throughout the initial ascent, constant velocity, and arrival at the next floor. And this particular challenge can be used nearly anywhere—for example, strapped to students' torso while they practice leaps in a dance studio or ride roller coasters on a field trip to an amusement park.

**FIGURE 3**

**Changes in g-force on an elevator.**


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**FIGURE 4**

**An Atwood machine.**

As the mass on the left falls, the smartphone measures its acceleration as it moves upward.


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## *Challenge #3: Acceleration in the lab*

Traditional Atwood's machines (Figure 4)—devices that typically include two connected masses with at least one suspended vertically—also pose conceptual difficulties for students. This is because students fail to understand the apparatus as a system of forces and because calculated accelerations are usually verified through an indirect method, such as a kinematics equation or sonic motion detector. The machine can be simplified by using the mobile device itself as an accelerating mass.

For this challenge, help students select a counterweight only slightly less or more massive than the mobile device itself—so that a decent acceleration can be measured and the mobile device won't move so quickly that it might be damaged or injure a student. Students find that more massive systems with equal net forces have a smaller acceleration, and vice-versa. This experience allows students to derive Newton's second law quantitatively through their inquiry experience by observing the effects of modifying system mass or net force (one at a time), as specified by *NGSS* performance expectation HS-PS2-1 (see box, p. 38). Teachers can also use this tool as an assessment. Once students have predicted the estimated acceleration of the entire system using the known masses, they can verify the results directly by looking at the acceleration reading on the mobile device.

## *Challenge #4: Centripetal acceleration while dancing*

Another concept physics students often misunderstand is centripetal force. Because of the observation that objects will "fly away" if spun quickly and released, most people refer to a fictional *centrifugal force.* To overcome this misconception, students should hold their mobile device outward at arm's length while smoothly spinning with their bodies as the center of rotation, much like a ballerina pirouettes (Figure 5). Students can then determine the direction of the acceleration and should infer from the graph that the net acceleration (and therefore the net force) is directed inward, toward the center of rotation.

Students can also qualitatively determine the relationship between centripetal acceleration and tangential velocity by spinning more and more quickly and observing that the centripetal acceleration increases—helping them understand the relationship, where $a_c$ is centripetal acceleration, $v$ is tangential velocity, and $r$ is radius (i.e., arm length). Once students have fully derived the quantitative relationship through other instructional methods, they can use the known mass of the mobile device and the length of their arms to calculate both tangential velocity and centripetal force (again, using Newton's second law).

This experience supports later inquiries into a field-theory understanding of gravitation and an understanding of why acceleration due to gravity typically registers at 9.8 m/s/s. Students can prepare these calculations as annotations to screenshots of their data, as shown in Figure 6.

FIGURE 5

**Determining centripetal force.**

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### *Challenge #5: Locating the accelerometer with a turntable*

Although for large-scale experiments it is acceptable to assume that the accelerometer is located at the center of the phone, for small-scale ones, the fact that it's typically not in the middle of the device becomes problematic. Identifying the location of the accelerometer is a learning experience in itself, and this challenge can be overcome with the use of a turntable. In this challenge, students place a piece of paper on a turntable with the phone atop it, oriented so that its long edge travels tangent to the circle it makes (Figure 7, p. 39). The phone is then outlined on the paper so that the radius of rotation measuring the acceleration can later be compared to its placement within the phone. When the phone rotates about the center at a standard 33 rpm, a constant total centripetal acceleration results.

For this challenge, ask students to either determine total acceleration by doing vector addition for the acceleration in the $x$ and $y$ dimensions or to directly read the total acceleration output on the app. Using a variation of the equation for centripetal acceleration [$a_c = (2\pi f)^2 r$], where $f$ is the frequency of rotation, and $r$ is the radius of the circle at which that centripetal acceleration is measured by the sensor, students can solve for the $r$ that produces that acceleration and note the circle of that radius on the paper, using a pencil compass. The same procedure is then repeated with the phone mounted 90° to its original position, and the radius is again noted. The intersection of these circles is the location of the phone's accelerometer chip (Figure 8, p. 40).

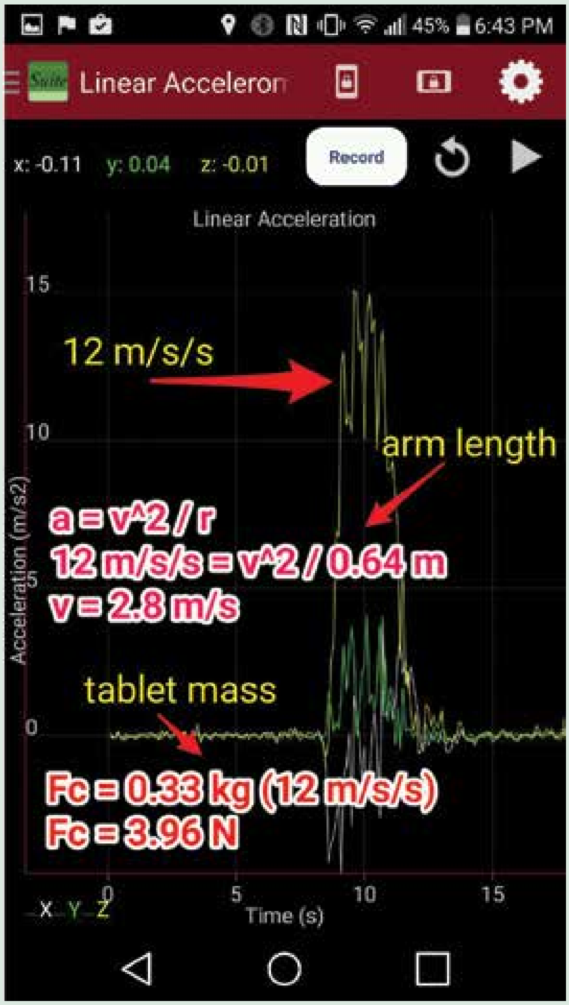
## Assessment

Because of the open-ended nature of data collection by mobile devices, formative assessment can be accomplished by working with students one-on-one or in small groups as they explain how the recorded accelerations relate to the kinesthetic activities they are doing with the device. Teachers can also use whiteboarding techniques, in which students display sketches of their graphs to the class and are encouraged to describe the cause of their data using Socratic dialog.

Lab practicals are another way to assess students and to incorporate engineering skills. Students can be given a set of materials with the Atwood machine, for example, and be asked to create a system that they predict in advance will accelerate as closely to 1 m/s/s as possible.

FIGURE 6

**Acceleration during a spin.**

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## Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

| | | |
|---|---|---|
| **Standard**<br>HS-PS2 Motion and Stability: Forces and Their Interactions | | |
| **Performance expectation**<br>The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectation listed below.<br>HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. | | |
| **Dimension** | **Name and *NGSS* code/citation** | **Connection to classroom activities** |
| **Science and engineering practice** | **Analyzing and interpreting data**<br>• Analyze data using tools, technologies, and/or models (e.g., computational or mathematical) to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-1) | In all of these challenges, students are expected to make sense of graphical data to determine the forces and interactions that caused changes in motion. For example, in Challenge #1, students need only identify the portion of the graph representing free fall, and in Challenge #5, they acquire appropriate data to determine the location of the accelerometer within the phone. |
| **Disciplinary core idea** | **PS2.A: Forces and motion**<br>• Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1) | In Challenge #2, students relate portions of an elevator ride (i.e., accelerated or constant velocity) to a measurement of g-force on a graph and see that g-force changes only during acceleration. In Challenge #3, they predict the acceleration of the mobile device based upon known forces acting on the system: the weights on each end of the string. |
| **Crosscutting concept** | **Cause and effect**<br>• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1) | In Challenge #4, students observe how multiple variables influence centripetal force, including the speed with which they spin the mobile device. |

More traditional, yet highly validated tests or portions of tests can be used for summative assessments, including the FCI (Hestenes, Swackhamer, and Wells 1992) or the Mechanics Baseline Test (Hestenes and Wells 1992), whose questions probe common misconceptions about the causes of constant velocity and uniformly accelerated motion, the graphical display of motion data, and the direction of forces acting on a system.

## Conclusion

The challenges described in this article directly engage students in data collection in various environments. These activities allow students to make meaning from data and to differentiate it from statistical noise that might be introduced, such as natural vibrations or the unsteadiness of a student's hand. Additionally, mobile-sensor data can be easily shared by exporting it through students' e-mail or via cloud sharing for later uploading into data-analysis software. For simpler data, students can simply share a screenshot.

If students must use their own mobile devices, some students may not have access to one and should be given an alternate assignment; or have the class work in small groups with a shared device. Give guidance about protecting privacy and personal passwords and taking care not to damage the device. Whenever possible, encourage parents to become involved in at-home data collection. We have found parents to be receptive, and students enjoy creatively collecting data and sharing their successes with their families.

Mobile devices not only help us better integrate technology in the classroom but also increase our opportunities for student achievement and engagement (ISED 2012). We hope you find the same to be true in your own classes. ■

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### On the web

Physics Toolbox Apps (Android and iOS): *www.vieyrasoftware.net*
Physics Toolbox Apps lesson ideas: *www.vieyrasoftware.net/#!lessons/c25a*
Engineer Guy Video: "How a Smartphone Knows Up from Down": *https://goo.gl/nr2rVn*
Challenge #1 worksheet: *https://goo.gl/a3V44o*
Challenge #2 worksheet: *https://goo.gl/rOjBJG*
Challenge #2: amusement park activity description and rubric: *https://goo.gl/I9b4kq*
Challenge #3 worksheet: *https://goo.gl/OlFHvQ*
Challenge #4 lesson plan: *https://goo.gl/xnhgW8*
Challenge #4 video: *https://goo.gl/Mv0mL0*
Challenge #5 lesson plan: *http://goo.gl/QlR5Aq*

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**FIGURE 7**

**Mobile device on a turntable.**

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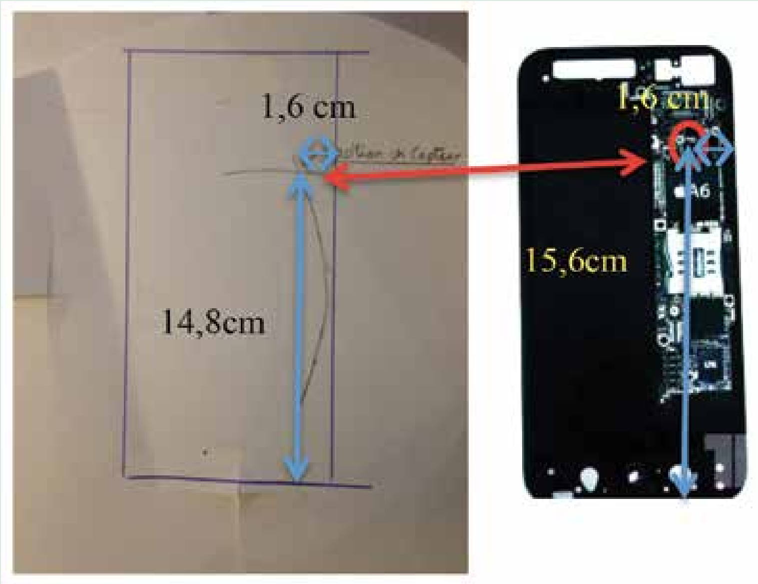
**FIGURE 8**

## Determining accelerometer location.

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