Patrick Foo (Department of Psychology) and Michael J. Ruiz, "Inexpensive Endoscope Activities," *Physics Education* **54**, 055005 (September 2019).

Inexpensive Endoscope Activities

Patrick Foo[1] and Michael J Ruiz[2]

[1]Department of Psychology, University of North Carolina at Asheville, Asheville, North Carolina, 28804, United States of America
[2]Department of Physics, University of North Carolina at Asheville, Asheville, North Carolina, 28804, United States of America

E-mail: pfoo@unca.edu and ruiz@unca.edu

Abstract

Students preparing to enter medical fields are required to take physics. To increase their interest in physics, a low-cost classroom medical activity is presented introducing them to the basics of endoscopic visualization and navigation. Incorporated in the activity are basic surgical techniques such as resection with single or multiple operators. Students also learn to appreciate the importance of physics since the endoscope works on the principle of total internal reflection. The tasks involve two pick-up tools with retractable claws available at hardware stores and an inexpensive endoscope with Bluetooth that sends video to student smart phones.

Introduction

The physics underlying the invention of the endoscope is the optical fiber. Optical fibers are based on total internal reflection, a topic encountered in introductory physics classes. The recent paper [1] by Alti in this journal, “Fun with optical fibers,” attests to the continued popularity of this important topic. The rich medical application presented here will help teachers rise to “the challenge of teaching introductory physics to premedical students” [2]. The supplement on medical physics by Chris Bishop for introductory students in the United Kingdom includes the endoscope among many fascinating uses of physics in the field of medicine [3].

The Endoscope and Physics

As mentioned in the previous section, the endoscope is based on total internal reflection. A necessary condition for total internal reflection is light traveling in a medium surrounded by a medium with a smaller index of refraction. When light reaches the interface from the inside at an angle greater than the critical angle, the light undergoes total internal reflection. See figure 1 for an example of total internal reflection, where green laser light is sent into smoked acrylic plastic. As the light inside the plastic reaches each boundary between the plastic and surrounding air with an incident angle greater than the critical angle, the light undergoes total internal reflection inside the plastic. The demonstration also works well enough with the typical red laser. Always use caution with any laser to avoid the direct beam and specular reflections.

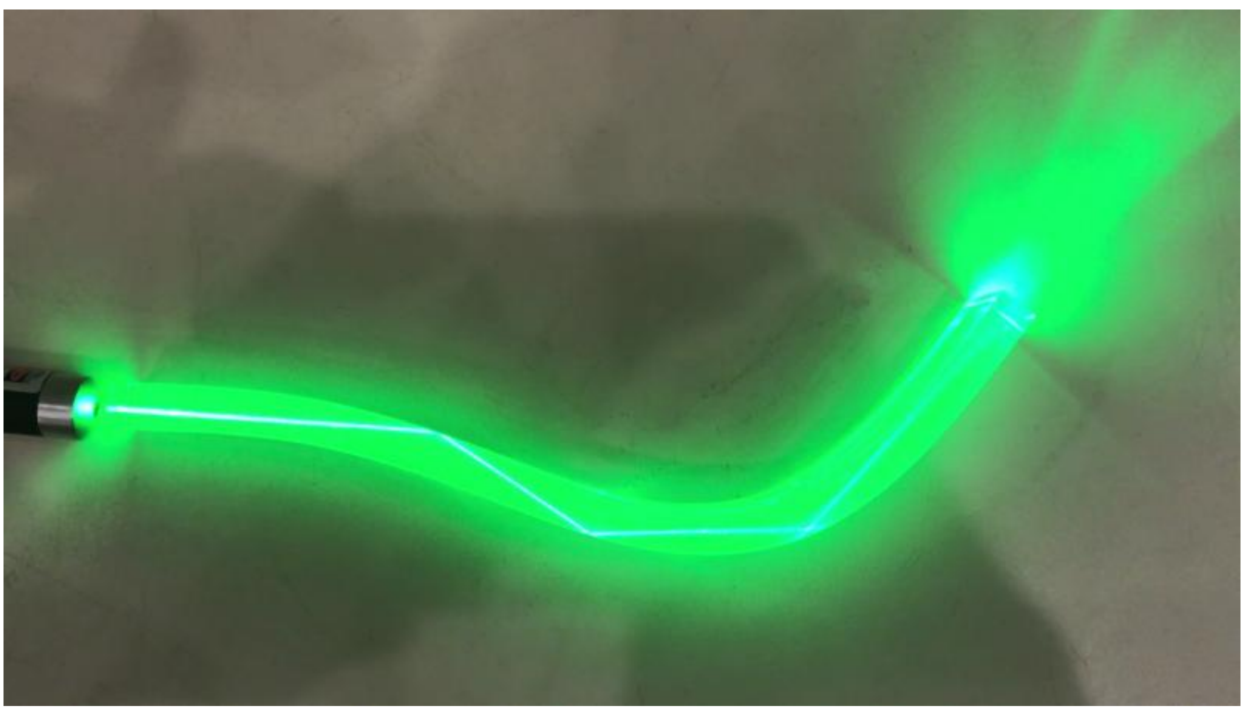


Figure 1. Total internal reflection inside smoked acrylic plastic. Smoked plastic has scattering centers so that the light path can be easily seen from the side. Safety Warning: Always use care with a laser to avoid looking directly into the laser beam or at specular reflections.

Light can be directed around a curved path by total internal reflection. Flexible optical fibers can be bent gently so that incident angles on the inside are greater than the critical angle. The critical angle occurs when the transmitted refracted beam leaving the plastic is 90°. Snell's law can be used to determine the critical angle θ_c :

$$n_{acrylic} \sin\theta_c = n_{air} \sin 90^\circ , \tag{1}$$

giving

$$\theta_c = \sin^{-1}\left[\frac{n_{air}}{n_{acrylic}} \sin 90^\circ\right] = \sin^{-1}\left[\frac{1}{1.5} \cdot 1\right] = 42^\circ . \tag{2}$$

Flexible fibres are used in optical communication such as transmissions for Internet access. Similarly, flexible fibres are found in the endoscope, where a composite optical fiber can be made of 30,000 smaller fibres packed in a coherent array to transmit images [3]. However, large critical angles are desirable so that light inside the optical fiber bounces off each interface easily near large grazing angles. In the design of fiber optics a cladding is wrapped around a fiber core where the cladding has an index of refraction just a little less than the index of refraction of the internal core fiber bundle. As an example, consider an index of refraction of 1.50 for the core and an index of refraction of 1.48 for the cladding [4]. Then, the critical angle is

$$\theta_c = \sin^{-1}\frac{n_{cladding}}{n_{core}} = \sin^{-1}\frac{1.48}{1.50} = 80.6^\circ . \tag{3}$$

Such a large critical angle restricts the signal to large angles of incidence and prevents broadening of the signal. The endoscope uses total internal reflection to first send light down a portion of the optical fibers and then transmits reflected images back to the surgeon along other fibers.

Medical Context

Advances in medicine and surgery aim for less-invasive techniques that can promote better outcomes and improved recovery times. These approaches include flexible endoscopic alternatives for visualization and surgical manipulation. The endoscope can be inserted through orifices of the body or through small incisions. Most well-known are surgical interventions in the upper and lower gastrointestinal tract, respectively esophagogastroduodenoscopy and colonoscopy. Other common examples include the female reproductive system (gynoscopy), and the interior of joints (arthroscopy).

The endoscopic technique is also opening new possibilities in treating tumors located along the ventral (underside) surface of the brain (such as the midline brainstem) through endonasal neurosurgery [5,6]. While Virtual Reality (VR) simulators (such as the phone apps TouchSurgery, Edoscopy3D and GastoEX) offer students lifelike visualizations of surgical procedures, they do not expose students to the hand-eye coordination inherent in these techniques. Alternatively, in this paper, we utilize largely off-the-shelf equipment that can serve as an introduction to single and dual person surgical techniques in a classroom of introductory physics.

While the equipment is primitive compared to sophisticated medical devices in hospitals, this low-cost classroom exercise introduces students to the basics of endoscopic visualization and navigation. The activities also give students hands-on experience of basic surgical techniques like resection with single or multiple operators.

Endoscope Setup

The basic equipment for a classroom endoscope demonstration is shown in Figure 2. An inexpensive endoscope with Bluetooth camera can readily be found on Amazon.com. The endoscope includes with its optical fiber, a Wi-Fi camera and an LED light source. The video from the endoscope camera can be transmitted to an iPad, computer, or smartphone. A flexclaw, an inexpensive grabber with a claw available at a hardware store, also appears in Figure 2. The molecular model balls are viewed by the endoscope camera and transmitted to the iPad or student iPhone. Later, the molecular model objects will be placed in a box for a student to locate and extract the water molecule. The instructions that come with the endoscope give the details on how to interface the endoscope Bluetooth camera with a computer, iPad, or smart phone. Therefore, students in class with their own iPhones can each tap into the video feed after downloading a free app.

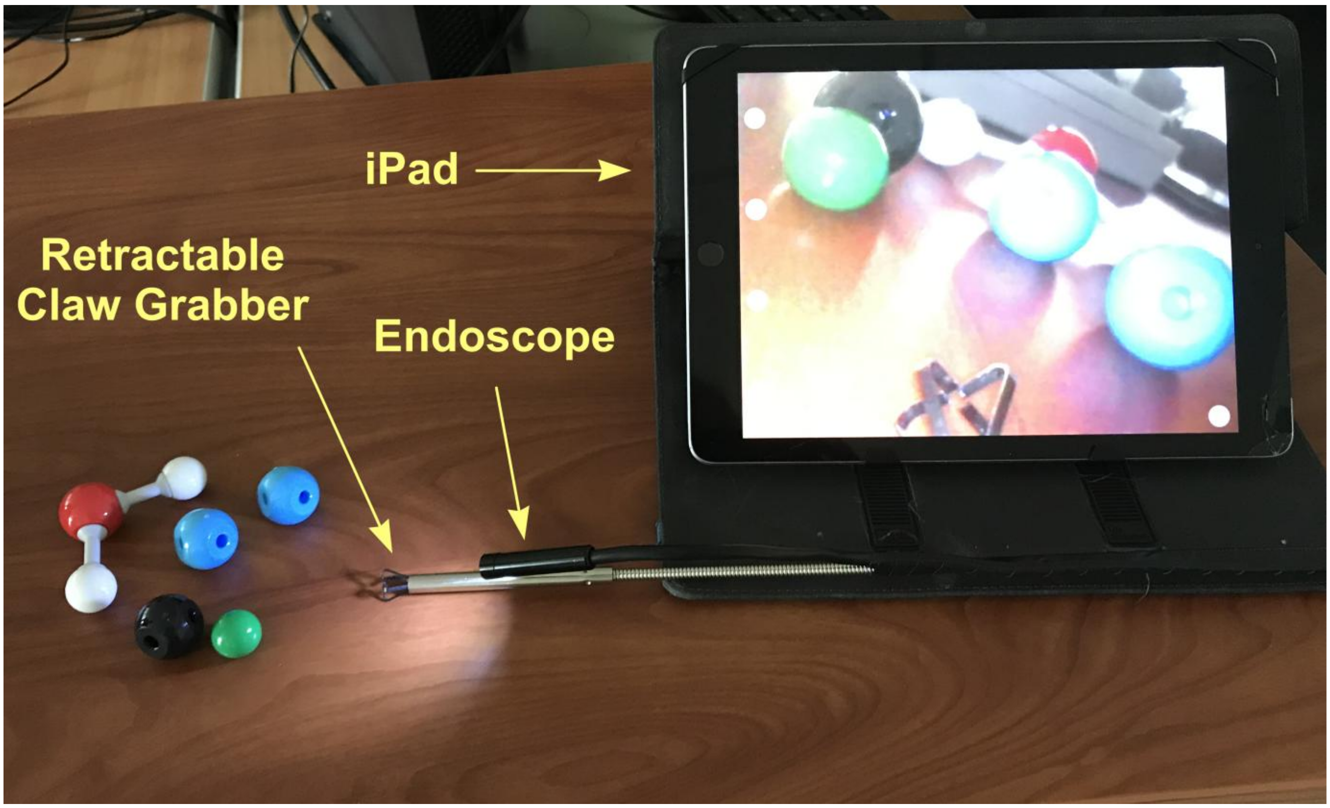


Figure 2. Endoscope with Bluetooth camera, iPad, and retractable claw grabber. The molecular model balls are viewed by the endoscope camera and transmitted to the iPad.

Other accessories can be found online for the endoscope. These additions include angled mirrors and manipulators. Our classroom demonstration employs two grabbers with a retractable claw. A grabber holding a model water molecule is shown in figure 3. Note that the endoscope has been pulled up at the end near the grabber in order to make navigation with the endoscope/grabber easier when inserted into a dark box. The raised endoscope gives a better view of the objects the camera points at. The student is then introduced to a crude version of the skill that doctors master with smaller probes and tools after much practice in medical schools and internships.

Figure 3. Endoscope and grabber holding water molecule with Bluetooth image transmitted to the iPad. Note that the endoscope has been pulled up near the grabber to make viewing and navigation easier.

Classroom Activities

Objects are placed in a closed box for the classroom activities. The student inserts the endoscope with the grabber through an opening in the box as illustrated in figure 4. The student in this figure is Everett, son of coauthor Patrick Foo. He carefully observes the video image on the iPad, guiding him as he searches for the water molecule inside the closed box. When found, his task is to grab one of the atoms so that he can lift the water molecule model out of the box. The lid of the box is removed as he finally retrieves object from the box.

Figure 4. Everett, son of coauthor Patrick Foo, inserts the endoscope and grabber into a covered box in search of the water molecule. Everett carefully views the iPad screen to guide him.

Another task involves multiple manipulators to give the student a basic hands-on experience of two surgeons working together to perform a medical operation. The task is for one student to grab part of an object to hold it in place while the second student extracts something from the object. See figure 5 for an illustration of the operation to be accomplished inside the dark box. One student holds a pack of gum while the second student pulls out a single stick of gum.

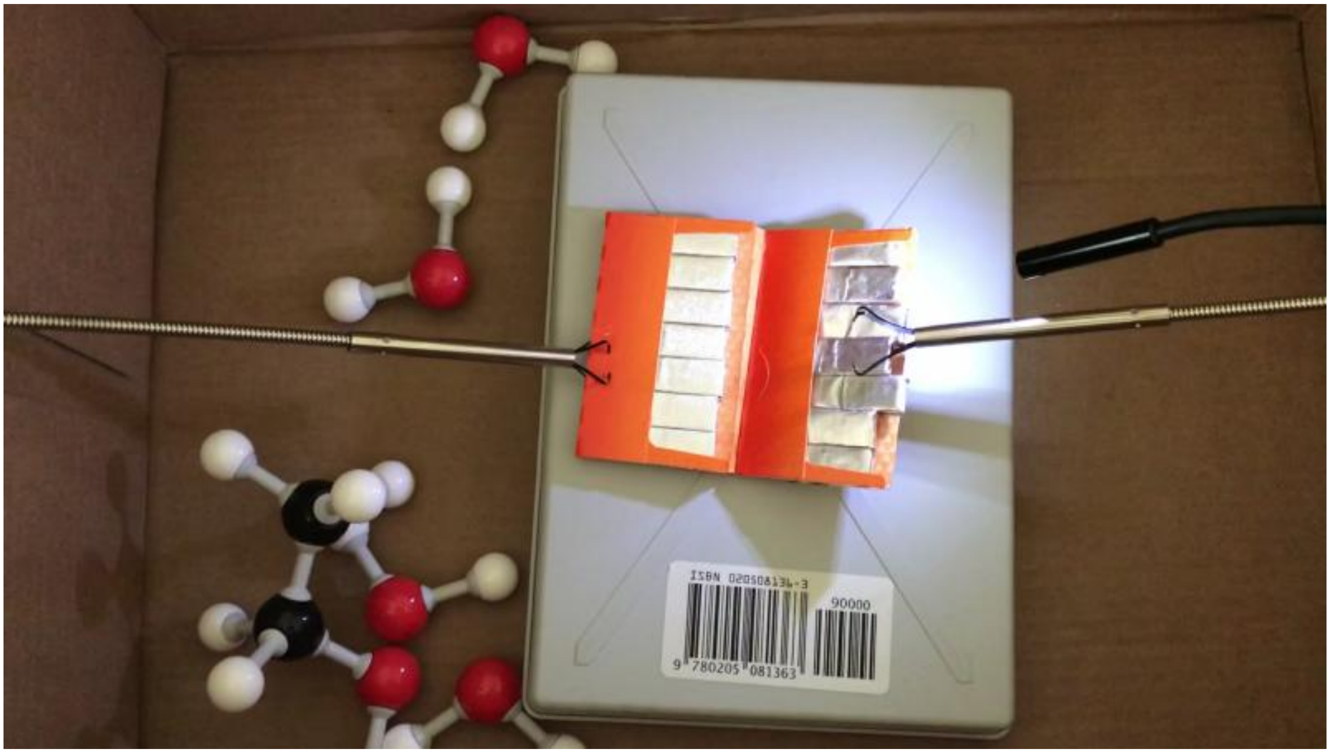


Figure 5. Task involving two students to be accomplished inside a closed dark box. One student must grab and hold one side of the pack of gum while the second student removes a stick of gum.

The camera provides the usual video feed to the iPad, but this feed must also be sent to the smart phone of the second student so that both students can see what they are doing remotely inside the dark box. Note that one student enters from the left end of the box while the other uses the right end. The endoscope is with the grabber on the right side. The view seen by the student on either the iPad or smart phone is shown in figure 6. The video feed can be sent to every student smart phone in the class so that everyone gets an excellent view of the action on their own phones.

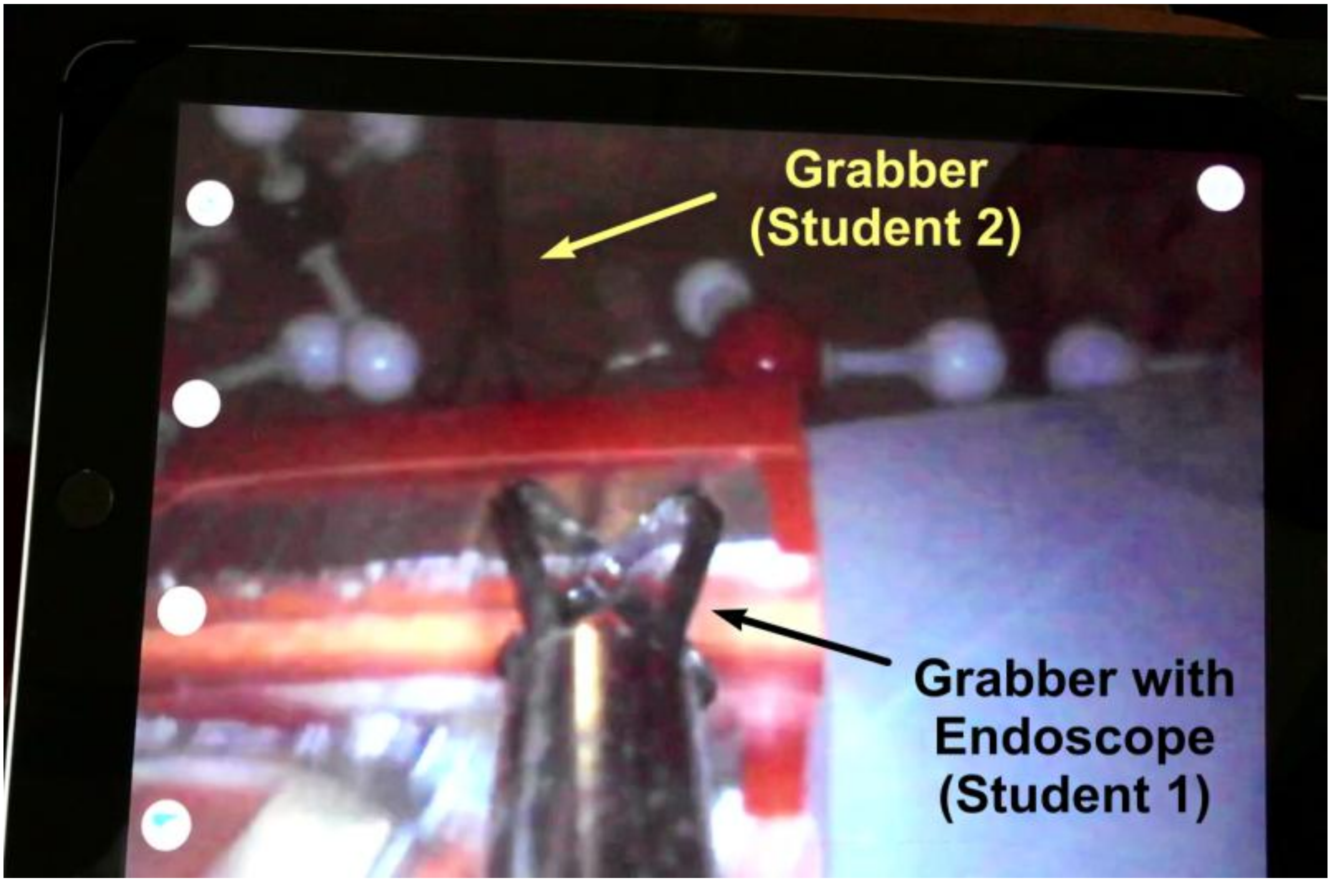


Figure 6. Two students working together. The first student extracts a stick of gum while the second student holds the pack of gum in place. The endoscope camera is next to the grabber of the first student. The video feed can be transmitted to every student smart phone in the class.

Conclusion

The fundamental physics of the endoscope has been presented along with classroom activities that use an inexpensive endoscope with Bluetooth. The Bluetooth allows the camera video to be sent to any number of computers, iPads, or smartphones. Students acquire hands-on experience manipulating grabber claws in conjunction with the endoscope as they search for objects in an enclosed box. The camera video fed to multiple smart devices is important so that two students can engage in exploration with the endoscope watching from their individual smartphones. The fact that the video feed can also be sent to each student smartphone in the class insures that everyone can watch the action. The task with two students introduces students to the kinds of cooperative coordination necessary for successful endoscopic neurosurgery with more than one surgeon. A video is included for the reader to see the fun classroom activities in action. [7]

References

[1] Alti K 2017 Fun with optical fibres *Phys. Educ.* **52** 045015

[2] Kortemeyer G 2007 The challenge of teaching introductory physics to premedical students *Phys. Teach.* **45** 552-7

[3] Bishop C 2016 *AQA A-level Physics Year 2 Student Book, Book 2* (*Collins AQA A-level Science*) (London: HarperCollins) p 35

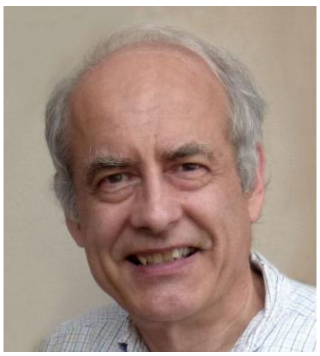
[4] Crisp J 2001 *Introduction to Fiber Optics* 2nd edn (Oxford: Newnes) pp 32-3

[5] Marigil M, Almeida J P, Karekezi C , de Almeida J R, and Gentili F 2018 Expanded endoscopic endonasal approach for resection of intradural chordoma: surgical and anatomic nuances: 2-dimensional operative video *Operative Neurosurgery* opy385 DOI: 10.1093/ons/opy385

[6] Marsh H 2014 *Do No Harm: Stories of Life, Death, and Brain Surgery* (London: Weidenfeld & Nicolson)

[7] Ruiz M J 2019 *Video: Inexpensive Endoscope Activities* (http://mjtruiz.com/ped/endoscope/)

Patrick Foo is an associate professor of psychology and co-founder of the neuroscience minor at the University of North Carolina at Asheville (UNCA), USA. He received his PhD in complex systems and brain sciences from Florida Atlantic University, USA.



Michael J Ruiz is professor of physics at the University of North Carolina at Asheville (UNCA), USA. He received his PhD in theoretical physics from the University of Maryland, USA. His innovative courses with a strong online component aimed at general students have been featured on CNN.

Our assistant, Everett Foo is the son of coauthor Patrick Foo. Everett is 11 and a student at Ira B. Jones Elementary School in Asheville, NC, USA. He plays electric guitar, and his *FIRST (For Inspiration and Recognition of Science and Technology) Robotics* team won a national Innovation Award early in 2019, USA.