Teacher Toolkit - Refraction and Snell's Law

Objectives:

1. To describe the conditions and the cause of refraction and to identify the one exception in which light crosses a boundary without bending.
2. To use information about the media (optical density, light speed, and index of refraction) on opposite sides of a boundary in order to predict the direction that light bends at that boundary.
3. To explain the empirical basis for Snell's Law of refraction.
4. To use Snell's Law to mathematically analyze situations involving the refraction of light at a boundary.

Readings:

The Physics Classroom Tutorial, Refraction and the Ray Model of Light Chapter, Lesson 1

The Physics Classroom Tutorial, Refraction and the Ray Model of Light Chapter, Lesson 2

Interactive Simulations:

1. Least Time Principle http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Least-Time-Principle
   The Least Time Principle is the premise that light always follows the pathway between two locations that takes the least amount of time. This interactive uses the classic analogy of a lifeguard trying to reach a drowning swimmer. The lifeguard can move faster on land than swimming in the ocean, so the pathway of least time is crucial. The interactive is intended for use with the accompanying Student Activity.
2. Refraction http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction
   This mobile-friendly sim is a great choice for the early phases of a unit on refraction. You can vary the medium of either the top or bottom substance (or both), fire the laser, and watch how the incident ray bends at the boundary. The companion Student Exercise is an inquiry-based activity that requires learners to figure out which variables to control in order to collect specific data.
3. PhET: Bending Light https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
   The HTML5 version of the Bending Light simulation includes some new features. In its basic form, students explore the refraction of light between two media. Newer features include Speed, Time, and Light Intensity tools to investigate how speed and wavelength of light change in different media.

Video and Animation:

1. The Index of Refraction and Snell's Law http://wosu.pbslearningmedia.org/resource/ate10.sci.phys.energy.lprefract/the-index-of-refraction/
   This PBS multimedia collection explores light refraction at the boundary between materials with short videos on refraction and Snell's Law, two interactive animations, a lab activity to measure the index of refraction, and a video that illustrates the importance of Snell's Law in fiber optics.
2. Mindset Learn: Refraction of Light https://www.youtube.com/watch?v=g8KWrqbOx00
   This 18-minute video is a good choice for students who are struggling with the content. It features engaging actors, multiple representations, and liberal use of analogy in explaining the refraction.
3. LearnCoach: Wave Refraction https://www.youtube.com/watch?v=487pOjwCauc (Part 1)
   This two-part video tutorial addresses refraction phenomena in terms of the wave nature of light. Part 1 focuses on the basic knowledge required to apply mathematics to problems relating to refraction. Part 2 may have less application in your classroom, but it's worth a look. It uses water waves moving from deep-to-shallow water to illustrate that waves travel faster in deep water and slower in shallow water.
4. LearnCoach: Ray Refraction https://www.youtube.com/watch?v=elG6-ZgO0OI (Part 1)
   This two-video package addresses refraction phenomena in terms of the particle nature of light. **Part 1** takes learners step-by-step through each component of Snell's Law, from how to measure incident and refractive angles through set-up and solution of the related equation. **Part 2** looks at the meaning of total internal reflection and how to use the critical angle to solve a related problem.
5. Sixty Symbols: Why Is Light Slower in Glass? https://www.youtube.com/watch?v=CiHN0ZWE5bk
   This set of dual videos presents a classical and quantum view of what happens when light traveling in air interacts with matter. You won't need to grapple with the math of quantum mechanics -- just open your mind to the possible explanations of **why** light is slower when it hits the boundary between air and glass.
6. Reflection and Refraction of Colored Light https://www.youtube.com/watch?v=2kBOqfS0nmE
   This video helps students visualize the relationship between light reflection and refraction as different colors of filtered light reach the boundary of water and air. The apparatus used was a Leybold 464-261, a device used to demonstrate refraction and reflection phenomena as a light beam crosses the boundary from water to air.

Reference Material

1. Refractive Index Database http://refractiveindex.info/
   This comprehensive database provides a treasure trove of free information on the refractive indices of inorganic and organic materials, glasses, alloys, liquid crystals, semiconductors ... and the human liver and colon.
2. Biography: Willebrord van Royen Snell http://www-history.mcs.st-and.ac.uk/Biographies/Snell.html
   This web page by John O'Connor and Edmund Robertson of University of St. Andrews, Scotland provides an engaging and very human glimpse of Snell and his contributions during his short life in the 17th Century.
3. Photonics: Geometrical Optics https://spie.org/Documents/Publications/00%20STEP%20Module%2003.pdf
   This free-access textbook offers an introduction to the basics of light reflection and refraction, and applications of geometrical optics in mirrors, lenses, and fiber optics.

Labs and Investigations: http://www.physicsclassroom.com/lab/refrn/RLlabs.cfm

1. The Physics Classroom, The Laboratory, Lab RL1 - Refraction Action
2. The Physics Classroom, The Laboratory, Lab RL2 - Direction of Bending
3. The Physics Classroom, The Laboratory, Lab RL4 - How Much?
4. The Physics Classroom, The Laboratory, Lab RL5 - The Unknown n

Demonstration Ideas: **See Complete Toolkit on our Website for Additional Details**

1. Brit Lab: How Does Light Bend? https://www.youtube.com/watch?v=tWy2QfC9APM
2. Quantum Boffin: Snell's Law of Refraction https://www.youtube.com/watch?v=yfawFJCRDSE

Minds On Physics Internet Modules: http://www.physicsclassroom.com/mop

The Minds On Physics Internet Modules are a collection of interactive questioning modules target student conceptual understanding. It includes detailed help that addresses the various components of every question. Refraction and Lenses Module:

1. Ass't RL1 - Meaning and Cause of Refraction
2. Ass't RL2 - Light Speed and Refraction
3. Ass't RL3 - Optical Density, Index of Refr'n, and Refr'n
4. Ass't RL4 - Snell's Law

Concept Building Exercises: http://www.physicsclassroom.com/curriculum/refrn

The Curriculum Corner, Refraction and Lenses Unit:

1. Light Refraction
2. Direction of Bending
3. Snell's Law

Problem-Solving Exercises: http://www.physicsclassroom.com/calcpad/refrn/problems

1. The Calculator Pad, Refraction and Lenses, Problems #1 - #12

Science Reasoning Activities: http://www.physicsclassroom.com/reasoning/refraction

1. Science Reasoning Center, Refraction Section, Reflection and Transmission
2. Science Reasoning Center, Refraction Section, Snell's Law

Real Life Connections: **See Complete Toolkit on our Website for Additional Details**

1. PBS Learning Media: ICT Center – Fiber Optics
2. Corning Inc. – Fiber 101
3. The Fiber Optic Association: Where are the Jobs in Fiber Optics?

Elsewhere on the Web **See Complete Toolkit on our Website for Additional Details**

1. Refraction of Light Home Labs http://k12.phys.virginia.edu/Labs/Lab05.pdf

Standards:

A. Next Generation Science Standards (NGSS) – Grades 9-12

Crosscutting Concepts: Patterns, Structure and Function

Science and Engineering Practices

Practice #2: Developing and Using Models
Practice #3: Analyzing and Interpreting Data
Practice #4: Using Mathematics and Computational Thinking
Practice #5: Constructing Explanations
Practice #8: Obtaining, Evaluating, and Communicating Information

Nature of Science