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Teaching unit: The Vision Mechanism: From Light to the Brain

DiFC - University of Palermo

BIOS4YOU AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS THANKS TO THE USE OF AUGMENTED REALITY

Project Number: KA220-BW-23-30-126516

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General topic of the learning path	The Vision Mechanism: From Light to the Brain
Specific name of the learning unit	Biology of vision and optics; signal transduction; from the eyeball to the visual cortex
Age of the target users	17–19 years old
Requirements for the learner	Basic knowledge of biology (anatomy of the eye, nervous tissues), physics (geometric optics: reflection, refraction, focusing), and introductory elements of electrophysiology.
Description of the learning unit	The unit guides students and teachers through a multidisciplinary pathway that integrates biology and physics to understand how light reflected from objects is focused on the retina, transduced by photoreceptors (cones and rods) into electrical signals, and transmitted along the optic nerve to the cortical areas responsible for vision. The use of digital and AR tools is intended to make otherwise invisible processes visible (activation of photopigments, routing of neural signals), clearly and progressively linking anatomical structures with physical principles.
Subject: Parties involved	Biology, Neuroscience, Physics (Optics), Technology (visualization/AR)
Keywords	Vision; Retina; Cones and rods; Signal transduction; Optic nerve; Refraction; Focusing; Visual cortex; AR; Scene-based learning
Key qualifications, skills and knowledge that can be acquired	• Reasoning & problem solving on integrated biophysical processes

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	• Design thinking applied to sequential and visual representations (scenes) • Practical knowledge: geometric optics, ocular anatomy, visual pathways • Digital/AR skills: 3D visualization, informative overlays, scene navigation
Resources and didactic aids used	AR platforms (e.g., Delightex Studio – Spaces, Marker), reliable web resources and educational videos, scientific articles and databases; 3D models (eye, retina/photoreceptors, optic nerve) and textual overlays for key data.
Assessment criteria and evaluation	Evaluation of knowledge (optic-biological-neural sequence), skills (cause-effect relationships between optical phenomena and biological responses), and competences (conscious use of AR tools, interdisciplinary integration).

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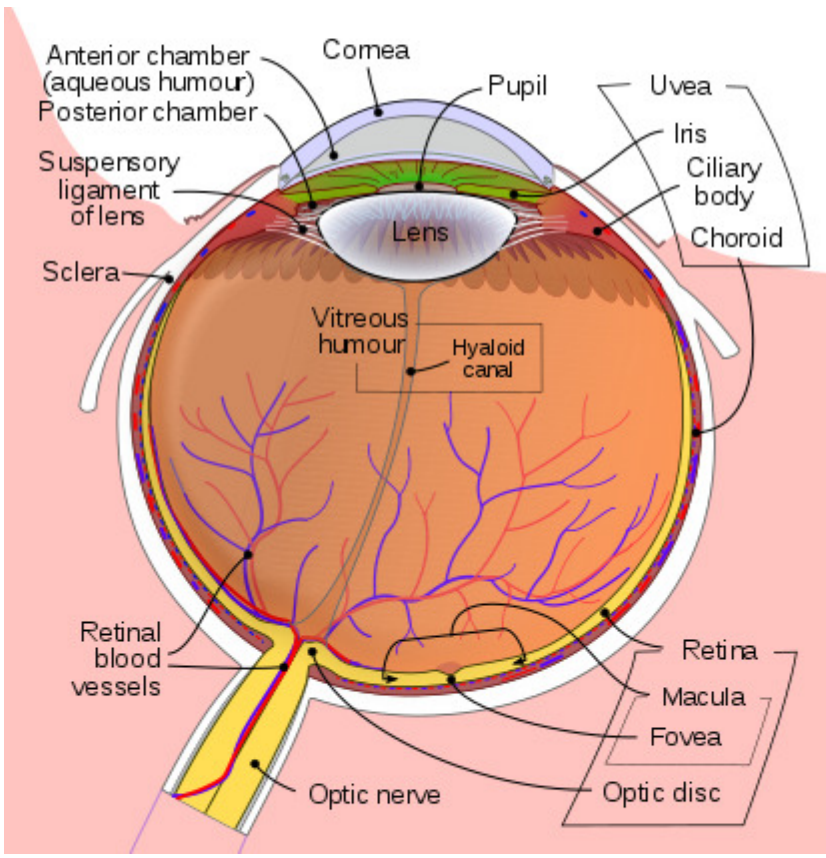
1. The Vision Mechanism: From Light to the Brain

Biology of vision and optics; signal transduction; from the eyeball to the visual cortex

Vision arises from the intersection of physical phenomena and biological processes. Light reflected from objects passes through the transparent media of the eye, is refracted, and focused on the retina. Here, photoreceptors convert luminous energy into electrical signals that travel along the optic nerve to the cortical areas responsible for visual processing. Seeing does not mean recording an image passively, but reconstructing it from signals that the brain interprets and integrates.



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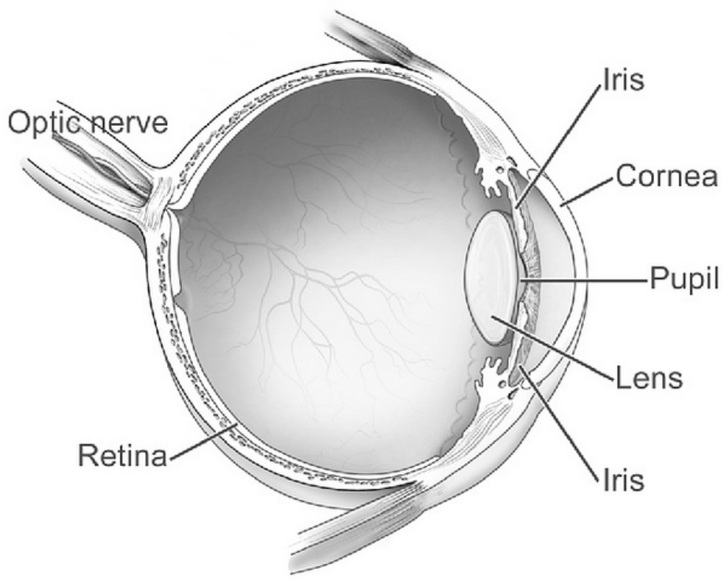

Focusing depends on the curvature of the surfaces and on the refractive indices of the ocular media. Geometrical or optical alterations lead to conditions such as myopia or hyperopia, in which the focal point falls in front of or behind the retinal plane. The crystalline lens contributes to accommodation, slightly changing its curvature to maintain sharpness at different distances.

The retina is a specialized neural tissue. Rods, which are highly sensitive, support vision under low light conditions; cones, less sensitive, enable color perception and sharp vision under daylight. Phototransduction begins when photopigments absorb photons and trigger a biochemical cascade that modulates the membrane potential of photoreceptors and subsequent retinal neurons (bipolar, ganglion, and interneurons).

From the retina, the axons of the ganglion cells form the optic nerve. The fibers partially cross at the optic chiasm, ensuring that the right visual field is processed mainly by the left hemisphere and vice versa. The signal proceeds along the optic tract to the lateral geniculate body (thalamus) and then reaches the primary visual cortex (V1), where, together with associative areas, it is analyzed and integrated to extract features such as shape, depth, motion, and color.

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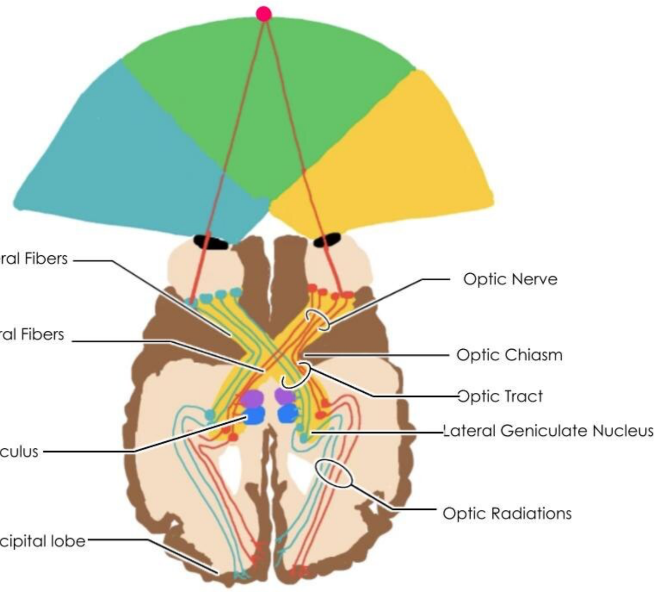

Perception is influenced by mechanisms of adaptation and by inferential processes. Adaptation allows the visual system to maintain sensitivity across a wide range of luminance levels, while visual illusions show that the brain interprets stimuli based on context and experience, completing partial information to reconstruct a coherent scene.

Binocular vision provides disparity cues essential for depth estimation, while monocular cues—such as relative size, perspective, occlusion, and shading—contribute to the three-dimensional perception even when only one eye is used.

From an educational point of view, it is crucial to clarify the sequence of events: (1) light is focused on the retinal plane; (2) photoreceptors convert light into electrical signals; (3) the retinal network pre-processes the signal; (4) the signal travels along the optic nerve and thalamic stations; (5) the visual cortex integrates the information to produce a perceptual representation. Presenting these steps in an ordered way helps students connect physical causes and biological effects.

The targeted use of digital and augmented reality tools makes it possible to visualize otherwise invisible processes, such as the path of light through ocular media, the activation of photoreceptors, and the transmission of signals along the visual pathways. Scene-by-scene visualization facilitates the understanding of relationships between anatomical structures and physical principles.

Let’s reflect together.
Why do we not see in the absence of light? How do the curvature of the crystalline lens and the refractive indices of ocular media affect image sharpness? How much does cortical interpretation contribute to our perception of color and motion? These questions help link observable phenomena to the underlying mechanisms.

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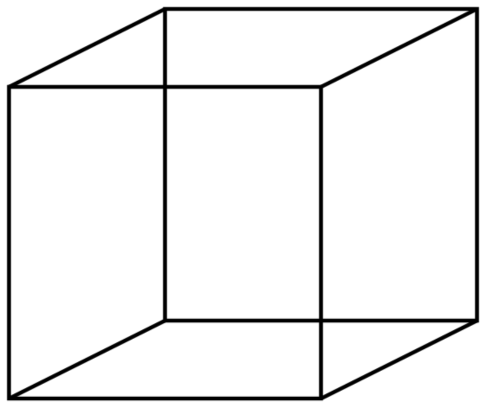
2. Explore Module

Engagement phase

Guiding question. *Do we see with our eyes or with our brain?*
The lesson opens with a brief visual stimulus: a picture in which the same surface appears to have different colors depending on the surrounding context, or a brightness illusion. The purpose is not to "deceive" students, but to introduce the idea that vision is not a mere optical recording—it is an **interpretation** of physical signals performed by biological structures.



Initial stimuli (videos and short resources)

How the Eyes Work – National Eye Institute (NEI): a clear overview of the main parts of the eye and the light path through the ocular media.
https://www.nei.nih.gov/learn-about-eye-health/healthy-vision/how-eyes-work

Our Eyes – Our Vision – Science Learning Hub: an accessible summary of the neural pathway from retina → optic nerve → brain.
https://www.sciencelearn.org.nz/resources/3006-our-eyes-our-vision

PhET – Geometric Optics (lenses/images): a short interactive exploration about refraction and focusing.
https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_all.html

Kick-off activity (5–10 min).
A quick projection of an optical illusion or a short video clip invites students to ask, *"Why do we see something that isn't there?"*
The goal is to highlight that vision is an **interpretative process** guided by the brain, not just an optical "input".
Suggested video: *How Vision Works* (Academy of Science – Curious)
https://www.science.org.au/curious/video/vision

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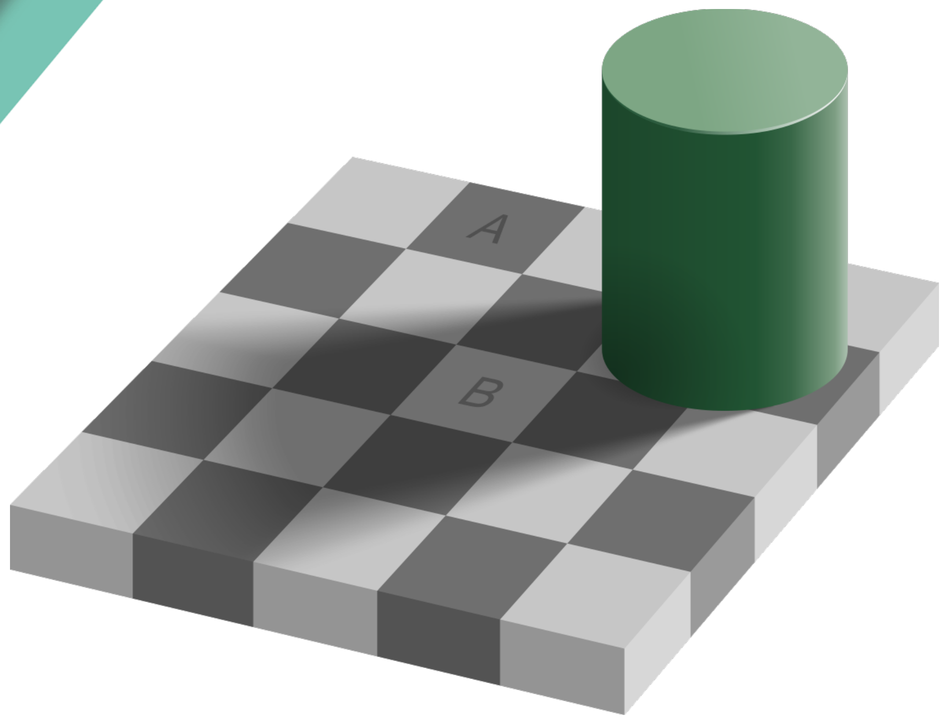

Brainstorming activities in the classroom

Leading question. Without light, there is no vision: what happens to light as it travels through the eye, and how does it become an electrical signal interpretable by the brain?

Prompting questions

What determines the focus of the image on the retina?
Refraction in the cornea and crystalline lens; the pupil regulates the amount of light; accommodation of the lens maintains sharpness at different distances.

Why do we perceive colors poorly in the dark?
Because the activity of rods predominates (high sensitivity but no color discrimination), while cones require more light to distinguish wavelengths.

Does the retina “record” a ready-made image?
No; the retina performs pre-processing (contrast, movement, direction), then the signal travels to the thalamus and visual cortex, where information is integrated.

Why are some objects sharp at a given distance and blurred at another?
Because the focal plane depends on geometry and refractive indices; when the image plane does not coincide with the retina, the image is out of focus (myopia/hyperopia).

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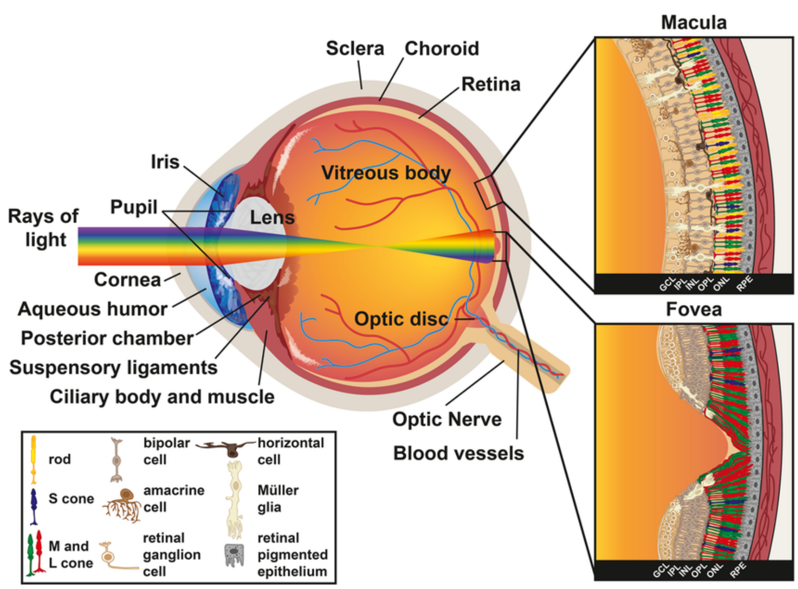
Micro-task.
Label the parts of the eye (cornea, pupil, iris, lens, retina, optic nerve) using a worksheet or an interactive resource.
Suggested resource: **Labelling the Eye** – Science Learning Hub
https://www.sciencelearn.org.nz/resources/3007-labelling-the-eye

Basic Level

Physics and Optics of Vision

Light, refraction, and image formation.
Vision begins when light reflected by objects enters the eye and passes through a natural optical system: cornea, aqueous humor, crystalline lens, and vitreous body. At each interface, light is refracted according to differences in refractive index. The result of this process is the **focusing of the image** on the retinal plane. The quality of the image depends on three main factors: surface geometry (curvature), refractive indices, and the pupil diameter controlling the depth of field. If light converges **before** the retina (myopia) or **beyond** it (hyperopia), the image appears blurred; the crystalline lens compensates through **accommodation** within physiological limits.



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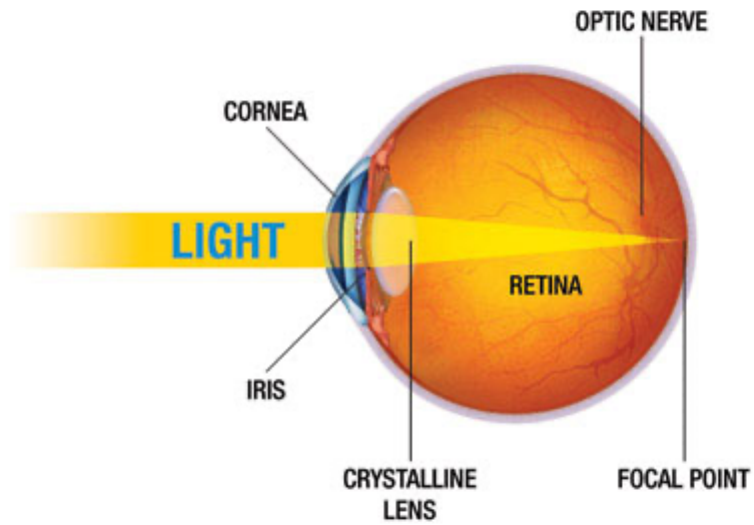
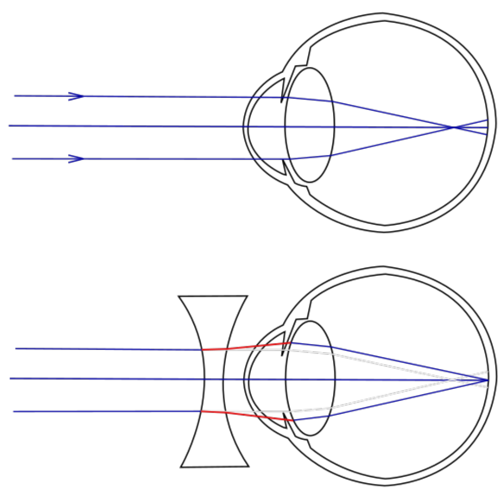


What determines where the focus will fall?
The balance between optical curvature and object distance: the closer the object, the greater the curvature required to maintain a sharp image on the retina.



From physics to physiology: photoreceptors and signal.

On the retina, the inverted image is not a final "snapshot": it is the physical stimulus that triggers **signal transduction**. Photoreceptors (rods and cones) contain photopigments that, upon photon absorption, change state and activate a biochemical cascade. The resulting signal is not an "all-or-nothing" action potential, but a graded potential transmitted to bipolar and ganglion cells. The axons of the ganglion cells form the **optic nerve**, the output channel carrying information to the brain.

Why can we distinguish large shapes in the dark but not colors?

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Because rods are more sensitive and active in scotopic (low-light) conditions but cannot detect color; cones, responsible for color and acuity, require higher luminance levels.

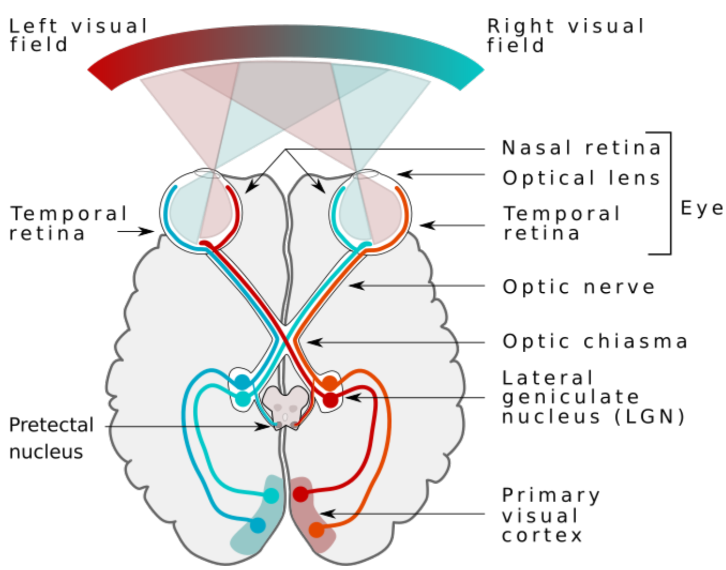
Spatial distribution and visual acuity.

Cones are densest in the **fovea**, where visual acuity is maximal and connections are more direct; rods dominate in the periphery, favoring the detection of movement and light variations. This trade-off explains why reading requires direct foveal fixation, while peripheral vision is more effective for motion detection.

Why do letters become less sharp when we fixate on a single one?
Because cone density decreases away from the fovea, and neural convergence increases: sensitivity improves, but spatial resolution decreases.

From the retina to the brain: mandatory stages.

The signal leaves the eye through the **optic nerve**, passes through the **optic chiasm** (partial decussation), continues in the **optic tract** to the **lateral geniculate nucleus** (thalamus), and finally reaches the **primary visual cortex (V1)**. Here—and in higher-order areas—the information is decomposed into features (orientation, spatial frequencies, motion, color) and then recomposed into a coherent perception. The brain does not "see" photons—it reconstructs meaning from neural activity patterns.



If the retina receives an upside-down image, why don't we see the world upside down?
Because perception is generated in the brain: the cortex interprets and reconstructs information regardless of the initial optical orientation.

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From theory to everyday objects.

The same principles operating in the eye are found in **glasses and contact lenses** (focus correction), **cameras and smartphones** (lenses, apertures, sensors), and **VR/AR headsets** (optics for near-display focusing). Bringing physics out of the lab helps understand not only *how* a lens works, but *when* and *why* optical correction is effective.

Let's reflect together.
Optimizing the retina is not enough: perception depends on subsequent processing. If the physical light remains the same, why do context and contrast change what we see? What does it really mean to "see with the brain"?

Web-based resources

How the Eyes Work - National Eye Institute (NEI)
https://www.nei.nih.gov/learn-about-eye-health/healthy-vision/how-eyes-work
Interactive explanation of ocular anatomy and light path through transparent media.

Photoreceptors: rods and cones - Khan Academy
https://www.khanacademy.org/science/health-and-medicine/nervous-system-and-sensory-infor/sight-vision/v/photoreceptors-rods-cones
Video lesson on photoreceptors and differences between scotopic and photopic vision.

Geometric Optics - PhET Interactive Simulations, University of Colorado Boulder
https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_all.html
Interactive simulation: observe how focus and magnification vary with distance and lens curvature; connect results to myopia, hyperopia, and accommodation.

Advanced Level

Fototrasduzione e adattamento.
The cascade occurring within photoreceptors (activation of photopigment, transducin, modulation of cGMP and ion channels) explains how light becomes current. **Adaptation** (to light and darkness) recalibrates the system's sensitivity, enabling operation across multiple orders of magnitude in luminance.

Resolution and contrast.
Acuity does not depend solely on optics: retinal and cortical circuits select **spatial frequencies** and **orientations**, enhancing contour contrast. The different pathways (parvocellular/magnocellular) prioritize **detail/color** or **motion**.

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Visual pathways and integration.
Beyond V1, processing splits into networks that emphasize **“what”** (form, color) and **“where/how”** (space, action). Color perception emerges from the integration of L/M/S cone responses and chromatic opponencies, while motion perception requires temporal integration and binocular disparity for depth.

Why do we perceive motion better than fine details under low light?
Because in scotopic vision, pathways sensitive to global and temporal variations dominate, with reduced spatial resolution.

Why can a small pupil sometimes improve sharpness?
Because it reduces aberrations and increases depth of field (within the limits of diffraction).

Flipped Learning:

Objective. Prepare for classroom discussion by understanding the sequence *light* → *retina* → *optic nerve* → *cortex* and the physics/biology connections.

Tasks (to be submitted as a 1–2-page report or 6–8 slides):

1. **Short reading** on the anatomy of the eye and the path of light. Highlight: cornea, pupil/iris, lens, retina, optic nerve.
2. **Worksheet “Cones vs. Rods”**: complete a table with *sensitivity*, *role in color/acuity*, *light conditions* (scotopic/photopic), *retinal distribution*.
3. **Geometric Optics simulation (thin lens):** create two screenshots —
    a. *Focused image* (focus on “retina”) with annotated parameters;
    b. *Out-of-focus image* (simulated myopia/hyperopia) with notes on how accommodation or corrective lenses restore focus.
4. **Short synthesis (max 120 words):** explain in your own words how the retina does not “record” ready-made images but **transduces and pre-processes** signals to be sent to the brain.
5. **Three debriefing questions:** one on optics (refraction/focusing), one on biology (phototransduction), one on perception (why don’t we see the world upside down?).

Submission. Upload the PDF or slides to the class channel before the lesson.

3. Operation Module

Basic Level

Understanding the visual process can be deepened through a series of practical activities that allow students to observe both optical and biological phenomena involved in the mechanism of vision. The aim

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of this section is to apply, in a guided way, the concepts of refraction, focusing, and signal transduction studied in the theoretical part, connecting the **physics of optics** with the **biology of the human eye**.

When light passes through media of different optical densities, its trajectory changes direction—a phenomenon known as **refraction**. The cornea and crystalline lens, which constitute the natural lenses of the eye, act as refracting elements that bend light rays to form a sharp image on the retina. Students can observe this behaviour using a simple experiment: partially immerse a pencil in a glass of water and notice how the object appears "broken" at the interface between air and water. This visual effect directly illustrates how light is deviated in ocular media and introduces the principle of refraction that governs the focusing of the retinal image.

The phenomenon is then explored in a virtual environment through the interactive simulation **Geometric Optics**, available on the **PhET platform – University of Colorado Boulder**:
https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_all.html

Through the simulation, students can vary the distance between object and lens and modify the curvature of the surfaces, observing how the position of the focal point and the image sharpness change. This activity helps students understand how the human crystalline lens changes its curvature to maintain the image in focus on the retina—a process known as **accommodation**.

From these observations arise essential questions: what is the relationship between lens shape and focusing distance? Why do excessive or insufficient curvatures lead to conditions such as myopia or hyperopia? Comparing the physical lens in the simulation with the biological crystalline lens clarifies how variations in refractive power affect the position of the focal point and, consequently, visual quality.
The focus then shifts to the retina, the thin sensory membrane at the back of the eye that converts light energy into electrical signals. Students analyse the arrangement of **photoreceptors**—cones and rods—and their complementary roles: rods are specialized for night vision and perceive changes in brightness, while cones provide colour perception and high acuity in bright light. The high density of cones in the fovea explains central sharpness, while the prevalence of rods in the periphery enhances motion detection.

The class discussion continues by analysing the behaviour of photoreceptors under low-light conditions. Why do colours appear faded at dusk? The answer lies in the higher sensitivity of rods, which enable vision in dim light but cannot discriminate wavelengths responsible for colour. This collective reflection helps students understand how the brain integrates information from different sensory cells to build a coherent visual representation.

Students are then invited to compare the human eye with everyday optical devices such as cameras or smartphones. The crystalline lens behaves like a converging lens, the pupil acts as a diaphragm, the retina functions as a digital sensor, and the brain plays the role of image processor. Through this analogy, vision is reinterpreted as a physical model connecting technology and biology.

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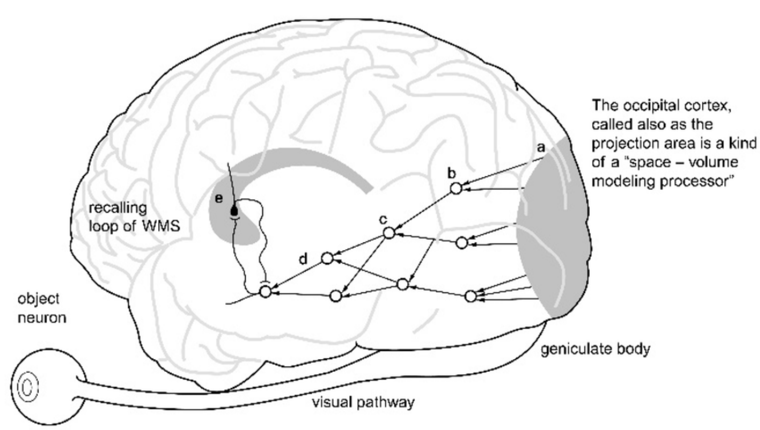
Let's reflect together. Vision is a complex process combining geometric optics and neurobiology. How does physics limit the quality of the perceived image? What strategies has the brain developed to compensate for the imperfections of the eye and ensure a stable and continuous perception of the external world?

Advanced Level

The advanced level deepens the connection between retinal transduction and the propagation of the signal along the neural pathways to the visual cortex. Students observe how light energy is converted into electrical signals within photoreceptors and how these impulses are transmitted through bipolar and ganglion cells to the optic nerve.

To understand the sequence of events, the concept of **phototransduction** is introduced: the absorption of a photon by a rhodopsin molecule triggers a conformational change that activates a biochemical cascade. This cascade reduces cyclic GMP, closes ion channels, and consequently hyperpolarizes the cell. The outcome is the transformation of light energy into variations in electrical potential.
The propagation of the signal along the optic nerve and its route toward the visual cortex is illustrated through an **Augmented Reality simulation** developed with **Delightex Studio – Spaces (Marker)**: https://edu.delightex.com/Studio/Spaces

Using mobile devices, students explore a three-dimensional model of the human eye, observe photoreceptor activation, follow the signal along the optic nerve, visualize fibre crossing at the optic chiasm, and finally see the projection of signals to the lateral geniculate nucleus and the primary visual cortex.



During the activity, guiding questions are proposed:
– At what point on the retina does light become an electrical impulse?
– Why do some fibres cross in the optic chiasm while others remain uncrossed?
– How does the visual cortex distinguish shape, colour, and motion?

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Answers emerge through group discussion and comparison between anatomical models and physical processes.
The lesson ends with a reflection on the evolution of artificial vision systems. Students compare the functioning of the human eye with that of a digital camera, highlighting analogies and differences. While the camera captures images through a sensor, the brain reconstructs perception by integrating information from multiple sensory sources and correlating it with past experience.

Let's reflect together. Do modern artificial-vision technologies truly imitate the mechanisms of biological vision, or do they merely reproduce its optical component while delegating interpretation to software? Does a machine actually *see*, or does it simply record?

Activities:

The concluding activities aim to consolidate learning and encourage peer collaboration. Students create a **concept map** representing the complete sequence of vision, from light to conscious perception, indicating for each phase the physical phenomenon, the anatomical structure involved, and the type of signal (light, electrical, or chemical).

Next, in small groups, they design a **mini Augmented Reality experience** using **Delightex Studio – Spaces (Marker)**. Each group illustrates a specific phase of the visual process, adding short explanatory texts, labels, and simple animations. At the end, the scenes are connected in sequence to reconstruct the entire pathway of vision.

To verify understanding, students complete an **interactive quiz** in AR consisting of multiple-choice questions on the stages of the visual mechanism.
The module closes with a **plenary discussion** in which students critically analyse the results obtained, compare their experiences, and reflect on the analogies between biological and artificial vision systems.

Expected output
At the end of the Operation Module, students should be able to describe in scientific language the full course of vision, link the principles of geometric optics with neurobiological processes, use digital and AR tools to represent complex phenomena, and develop a critical approach toward artificial-vision technologies.

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