

EXPERIMENT 1: Tables

Table S1: Examples of Standard Clinical Explanation and Teaching Analogy

Explanation	Analogy
<p>When a passageway – for example any of the airways in your lungs, including your bronchioles and trachea – is open, it allows fluids such as air to flow in an unobstructed manner. The air travels in discrete layers called ‘laminae.’ This is the most unobstructed way for the air to travel. However, a perturbation or disturbance can cause the layers of air to mix and individual particles to collide. This changes the flow from smooth and laminar to turbulent and chaotic. This property of fluids is called Goethe’s Law. The factors affecting flow and the transition between laminar and turbulent flow are: velocity, smoothness of the passageway, the thickness or viscosity of the fluid, diameter of the passageway, and density of the fluid. In the lungs for example, narrowing of the air passageways or mucus build-up can change air flow from laminar to turbulent, thus creating difficulties in breathing. This change from laminar to turbulent can be detected physically by the presence of noise – in our lungs, this is called wheezing. Asthma for example is characterized by wheezing which is a flow problem as the constriction of the air passageways causes air to move from laminar to turbulent flow (accompanied by wheezing). Goethe’s law applies in many situations.</p>	<p>A good analogy would be noise – gurgling – caused in water pipes due to mineral buildup or calcium deposits. The buildup disrupts laminar flow and decreases the speed of the water as well as pressure. There are other factors that affect flow. Any pathology that causes narrowing or obstruction of an airway will produce turbulent flow just as if you pinched a garden hose in the middle, you will lose water pressure.</p>

Table S2: Example Practice Vignette: **Goethe's Law**

Case (respiratory)	<p>A 3-year-old infant presents with a 4-week history of progressively worsening cough, shortness of breath following feeding and an unusual musical high-pitched sound with noisy breathing. He is the first born to a nurse and an accountant, born 3-months premature but otherwise through normal delivery. A chest x-ray revealed a slightly compressed trachea by a foreign body, which seemed to have disrupted the regular smooth flow of air particles. The effect of only a small amount of narrowing of the child's airway resulted in a significant (many-fold) increase in airway resistance as manifested by the abnormal breathing symptoms the child was experiencing. Explain how the obstruction caused the infant's breathing difficulties?</p>
Explanation provided to students	<p>The obstruction's main function is to change laminar air flow in the lungs to turbulent flow. By occluding or restricting the airway, the obstruction forces layers of air to collide with one another. This forces the student to generate more force per breath changes breathing into a wheezes. Goethe's law explains the symptoms in this case.</p>

Table S3: Sample test vignette and scoring guide

Far transfer Goethe (laminar flow) case

A patient with cancer receives radiation treatment to his abdomen which unfortunately includes his kidneys in the treated radiation field. While his cancer treatment is successful, several years later he returns to the hospital complaining he cannot produce urine. He develops chronic kidney failure and the physicians admit him for investigation. A kidney biopsy shows that scaring has caused consistent severe narrowing of around 60% where the filtering parts of the kidney join to the kidney’s urine carrying tubules. It’s shown there is virtually no fluid going down the tubules even though the tubules are not actually blocked. Which law best explains the findings and why?

Score	Law Selected	Written Response	Rationale
0	Starling’s law		Incorrect selection of law
1	Goethe’s Law	The restriction is a caused by the radiation which causes a block.	Incorrect explanation or weak explanation
2	Goethe’s Law	The persistent narrowing of the kidney is an issue of blocking flow – this causes a changing of the flow from laminar to turbulent and prevents smooth flow of urine	Correct law selected, some use of learning terminology
3	Goethe’s Law	With this degree of reduction of kidney tubules radius, what’s happening is a reduction of the flow due to change in the velocity. The block changes flow from laminar to turbulent and this reduces the ability of the urine to actually move through the tubule. Additionally, the blockage itself is an impediment to flow though the main is issue is the force of the urine.	Correct law selected, good use of learning terminology