# Stories Behind the Equations: Modular Historical Figure Packages

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**WIP: Stories Behind the Equations: Modular Historical Figure Packages**

**Abstract**
Engineering education has long emphasized mathematical rigor, analytical problem-solving, and technical precision. However, many students struggle to connect abstract equations with their real-world origins and applications. Without historical or experimental context, equations often appear as isolated formulas rather than representations of physical phenomena shaped by human curiosity and discovery. This paper introduces a pedagogical framework that seeks to bridge this gap through the development of modular Historical Figure Packages. Each package documents the life, experiments, and conceptual insights behind key equations in thermodynamics, fluid mechanics, and mechanics of materials, highlighting the people, experiments, and contexts that gave rise to foundational engineering principles.

Each Historical Figure Package consists of five core components: historical context, experimental origin, conceptual narrative, engineering impact, and classroom activities. The design goal is to create stand-alone, flexible, and scalable modules that faculty can easily integrate into existing courses with minimal preparation. This paper presents the first phase of an ongoing research study investigating the effectiveness of these packages in improving student conceptual understanding, engagement, problem-solving ability, and long-term knowledge retention, while also examining faculty usability and adaptability across courses. By embedding storytelling and history within technical instruction, this framework aims to humanize engineering education and strengthen students' connection to the discipline.

## 1. Introduction
Foundational engineering courses like Thermodynamics, Fluid Mechanics, and Mechanics of Material form the intellectual backbone of undergraduate mechanical engineering curricula. Yet many students find these courses procedurally demanding but conceptually opaque. Equations such as Bernoulli's equation, Hooke's law, or Fourier's law are often introduced as finalized mathematical expressions rather than the outcomes of human inquiry and experimentation. Students may become proficient at manipulating formulas while lacking insight into the assumptions, limitations, and embedded physical meaning.

This disconnect has implications for long-term learning. Students who cannot articulate why an equation takes its form or under what conditions it applies often struggle to transfer knowledge to solving novel engineering problems. They may also develop a narrow view of engineering as a discipline defined by calculation rather than creativity, curiosity, and discovery. The absence of historical context can reinforce the misconception that engineering knowledge is static rather than the product of evolving human understanding.

Ironically, many of the most fundamental equations in engineering bear the names of individuals whose work emerged from hands-on experimentation and conceptual struggle. Yet these stories are rarely integrated into instruction beyond brief anecdotes. This omission represents a missed opportunity to support conceptual understanding and to humanize engineering education.

This project introduces Historical Figure Packages, a structured pedagogical approach designed to reconnect equations with the people and experiments that produced them. The framework aims to provide instructors with modular, ready-to-use materials that can be integrated into existing courses with minimal preparation time. The broader goal is to help students see engineering knowledge as dynamic, evolving, and grounded in human experience.

## 2. Background and Related Work

Engineering education has long emphasized mathematical rigor, analytical problem solving, and technical precision. Yet a substantial body of scholarship argues that this focus, while essential, is incomplete without paying attention to the historical development of engineering knowledge. History provides a lens through which students can understand not only what engineers knew, but how that knowledge emerged, why it took the form it did, and what assumptions and values are embedded within it.

Matthews argues that historical case studies help students grasp the evolution of scientific ideas, making abstract concepts more intelligible, and reducing persistent misconceptions [1]. Niaz extends this argument by demonstrating that students who engage with historical controversies, such as competing models of heat, motion, or elasticity, develop stronger conceptual reasoning skills than those who encounter only polished, final-form equations [2]. Turns et. al. claimed that integrating humanistic perspectives, including history, helps students develop a richer sense of engineering identity and purpose [3].

Beyond engineering, STEM education research provides strong evidence that historical narratives enhance learning. Monk and Osborne argue that history of science helps students understand the nature of scientific inquiry, including the role of evidence, argumentation, and conceptual change [4]. Clough's work shows that historical stories help students appreciate the nonlinear, contested, and creative aspects of scientific progress [5]. Slykhuis et. al. demonstrate that historical reconstructions, recreating past experiments or debate, improve engagement and conceptual understanding [6]. Studies in science teaching indicate that historical case studies lead to deeper conceptual understanding and improve student attitudes toward difficult topics, even if they do not directly enhance rote recall [7]. Integrated STEM curricula that emphasize the historical development of STEM ideas have been shown to deepen students' understanding of subject matter by framing scientific concepts in their cultural and historical settings, facilitating richer meaning-making [8]. Integrating engineering with history in educational settings has been associated with improved analytical thinking, enhanced problem-solving skills, and increased motivation by helping students connect technical concepts with historical practice and real-world impact [9].

Despite this suggestive evidence, systematic research on the pedagogical impact of historical narratives, specifically within undergraduate engineering courses, remains limited. While multi-disciplinary narrative and storytelling approaches have been explored (e.g., narrative inquiry as a qualitative research method in engineering education), explicit historical integration to support conceptual mastery and professional identity formation is an emerging area of study [10]. The Historical Figure Package (HFP) framework builds on this emerging literature by offering a comprehensive set of modular, scalable resources, including course handouts and interactive hand-on activities instructions, designed for direct integration into existing engineering curricula with minimal instructor preparation.

## 3. Historical Figure Package Framework

### 3.1 Design Philosophy

The Historical Figure Package framework was developed around three guiding principles:

- Modularity – Each package is self-contained and can be used independently.
- Minimal Time Overhead – Designed for integration within 10–20 minutes of class time.
- Direct Alignment with Core Content – Historical materials are explicitly tied to equations already required by the course syllabus and included in lessons plans.

Rather than replacing them, these principles ensure that the framework complements traditional analytical instructions. The goal is to enrich and invigorate existing pedagogy without imposing additional burdens on instructors.

### 3.2 Package Structure

Each package includes five components:

- Historical context – The scientific era, technological challenges, and motivations.
- Experimental origin – Key experiments or observations that led to the equation.
- Conceptual narrative – How the original thinker reasoned through the problem.
- Engineering impact – Modern applications and relevance.
- Classroom activities – Prompts, conceptual questions, or small demonstrations.

This structure allows instructors to select components that fit their teaching style and course constraints, as each component can be introduced as a standalone unit at various phases in the lesson plan on a subject in its associated theoretical and experimental context. The modular design also supports scalability across institutions.

To provide early clarity on the scope of the current HFP library, Table 2 (later in the manuscript) summarizes the three courses involved and the key conceptual targets addressed in each. At this stage of development, the available packages include:

- Fluid Mechanics – Reynolds Number & Dynamic Similarity
- Thermodynamics – Carnot Efficiency & State/Path Function Concepts
- Mechanics of Materials – Hooke's Law and Elasticity

These details are elaborated further in Section 4.

## 4. Development and Early Examples

### 4.1 Course Contexts

The packages were developed for three foundational mechanical engineering courses: Fluid Mechanics, Thermodynamics, and Mechanics of Materials. These courses were selected because they contain equations with rich historical origins and because they represent conceptual bottlenecks in the curriculum. The development process involved reviewing historical sources, identifying conceptual bottlenecks, and designing narratives that align with course learning outcomes. The authors are planning to implement the developed HFP in Fall semester when the courses are offered.

### 4.2 Example Packages

In this section, the Reynolds package is used as an example to show the content.

*Historical context*
Born in 1842 during the height of the Industrial Revolution, Reynolds witnessed the rapid expansion of steam-powered machinery, when engineers faced critical failures: pipes burst due to unpredictable pressure surges, naval hull designs were suboptimal, wasting fuel and speed. There was an urgent need for scientific understanding of fluid mechanics to improve engine efficiency and safety. The challenge Reynolds faced was that engineering was primarily empirical, based on trial and error. Reynolds believed it must be grounded in rigorous mathematics and classical mechanics. He thought that theory and practice must be unified. Engineers needed both mathematical rigor and experimental validation to solve real-world problems.

*Experimental origin*
In 1883, in an attempt to understand the flow resistance under different dynamics conditions, Reynolds injected a thin streak of dye into water flowing through a glass tube. By controlling the flow rate, he revealed the hidden structure of fluid motion (Figure 1).

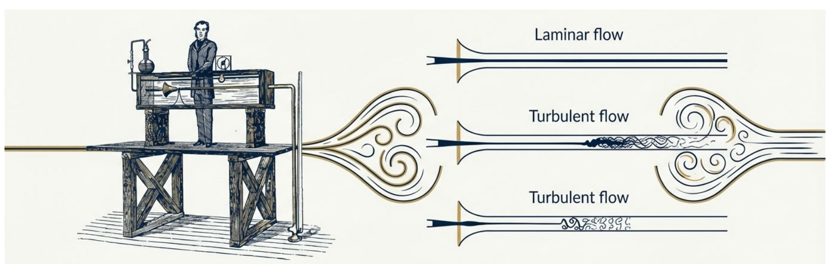


Figure 1. Osborne Reynolds' original dye injection experiment

*Conceptual narrative*
Reynolds framed the problem as a competition between two opposing physical properties: inertia force versus viscous force. By considering the compounding effect of fluid properties, flow velocity and tube size, Reynolds deduced a dimensionless parameter, the Reynolds' number ($Re$). It serves as a criterion to predict the type of flow in the tube: Laminar vs. Turbulent Flows.

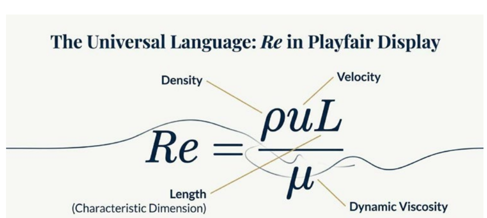


Figure 2. Reynolds number ($Re$) definition

*Dynamic Similarity*:
Reynolds realized that different fluids at different scales could behave identically if this dimensionless parameter (the Reynolds number) were held the same. This realization heralded modern aerodynamic and hydrodynamic testing. By maintaining the same Reynolds Number, engineers can accurately predict the behavior of a full-sized structure using a small-scale model while the physics remains identical regardless of size.

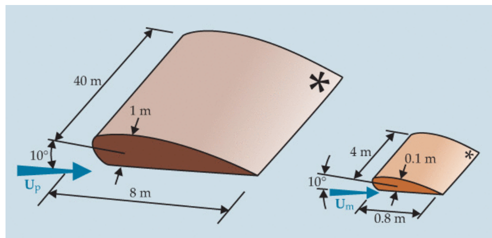

Figure 3. Dynamic Similarity: Lift and Drag over an Airfoil

Small-scale physical models also offer practical advantages for engineering testing. Because they require far less material, power, and facility space, scale models enable controlled wind-tunnel and water-tunnel experiments that would be prohibitively expensive or physically impractical with full-scale systems. This is one key reason dynamic similarity remains central to modern aerodynamic and hydrodynamic design.

To connect the concept to real-world applications, typical Reynolds numbers for real-world flows are presented in Figure 4.

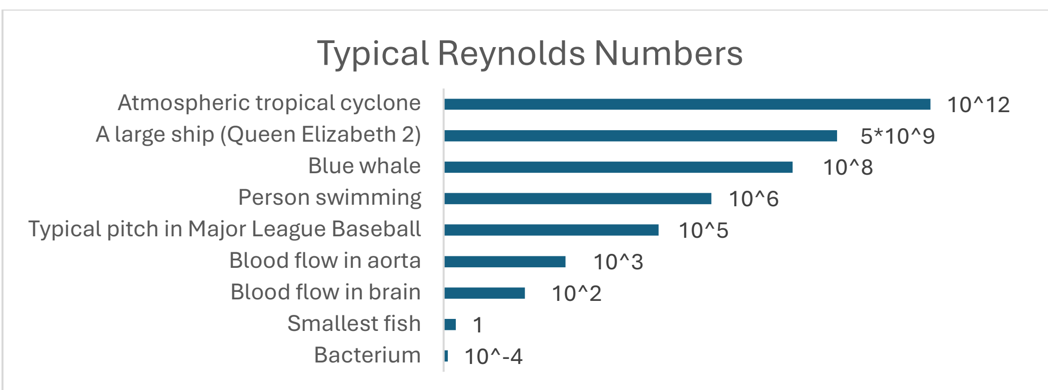

Figure 4. Typical Reynolds numbers in fluid dynamics

*Engineering impact*
From the microscopic flow in a lab-on-a-chip to the massive currents in the oceans, the Reynolds Number remains the universal metric for understanding fluid motion in the 21st century.

- Aerospace engineering: Reynolds number is used to design wings and fuselages by predicting airflow separation and drag. It is critical for scaling wind tunnel test results to full-sized aircraft.

- Automative design: Engineers use Reynolds number to optimize vehicle shapes, reducing aerodynamic drag to improve fuel efficiency and stability at high speeds.
- Biomedical engineering: Reynolds number is crucial for modeling blood flow in arteries and designing medical devices like artificial heart valves and stents to prevent turbulence-induced clotting.
- Environmental science: Reynolds number is applied in climate modeling and oceanography to simulate large-scale currents and atmospheric patterns, helping predict weather and climate shifts.

*Classroom activities*

Activity 1: The Syringe Visualization (laboratory activity)

Students can recreate Osborne Reynolds' famous 1883 dye experiment by using a clear tube and a syringe filled with food coloring. The primary challenge is for students to adjust the flowrate of water through the tube and identify the exact flowrate where the dye streak transitions from a steady line to a "wobble." This visualization experiment allows them to directly observe the three distinct regimes identified by Reynolds: Laminar, transitional and turbulent flows.

Activity 2: The Submarine Scaling Challenge

To test the concept of Dynamic Similarity, students are presented with a scenario: An engineer tests a 1/10 scale model of an underwater drone. If the prototype drone moves at 10 m/s, how fast must the test tunnel water move around the scale model to match the physics?

Insight: Students must recognize that if the model is 1/10 proportionally of the prototype, velocity $u$ must be multiplied by 10 to keep Re constant. This shifts the focus from "plug-and-chug" calculations to physical reasoning about how scale dictates fluid dynamic behavior.

Using scale models in this design context allows engineers to evaluate fluid forces, stability, and performance characteristics long before constructing a full prototype, reducing both development cost and design risk. This reinforces how dynamic similarity directly supports iterative design refinement.

Activity 3: "The Life of Low Reynolds Number" Discussion

This critical thinking exercise shifts the focus to how scale dictates physical laws. In low-Reynolds number flows, the viscous force dominates. Students can discuss why microscopic organisms, such as bacteria, cannot "coast" when they stop swimming. This highlights the concept that at very small scales, viscosity dominates the environment so completely that motion stops the instant the propelling force is removed – viscous force overwhelms inertia force (gravity). This activity could tailor to biomedical related majors.

To conclude these activities, students can relate their findings to modern technological applications where the Reynolds number is the primary metric for design and analysis. These include: Predicting drag on aircraft wings; Designing lab-on-a-chip diagnostic devices.

**Section 4.3 – Breadth of the HFP Framework**

To demonstrate the modularity and cross-disciplinary application of the HFP framework, Table 1 summarizes the conceptual mapping for two of the above-mentioned courses.

Table 1: Historical Narrative Mapping for Mechanics and Thermodynamics

| Figure / Equation | Historical Struggle (Context) | Conceptual Narrative (The "Aha!") | Targeted Misconception | Modern Impact |
|---|---|---|---|---|
| Robert Hooke $F = kx$ $\sigma = E\varepsilon$ | Perfecting the pocket watch to solve the "Longitude Problem" for navigation. | "Ut Tensio" Challenge" Realizing that internal material resistance is proportional to external displacement. | Confusing stiffness (geometry) with elasticity (material property). | Structural health monitoring; MEMS sensor design. |
| Sadi Carnot $\eta_{max} = 1 - \frac{T_c}{T_h}$ | Investigating why British steam engines were superior to French designs during the Napoleonic Wars. | Investigating why British steam engines were superior to French designs during the Napoleonic Wars. | The Water Wheel Analogy: Heat does not "disappear"; it "falls" through a temperature gradient to produce work. | Power plant efficiency; climate change and energy limits. |

## 5. Research Design and Methods

The research component of this project is structured as a multiphase study, of which the present paper focuses on Phase 1: Development of the Historical Figure Package framework. We describe the work on establishing a rigorous research design that will guide future evaluation once the packages are deployed and outcome assessments are conducted.

The study is grounded in constructivist and narrative-based learning theories, which suggest that students develop deeper, conceptual understanding when new ideas are connected to meaningful contexts. Historical narratives offer a natural mechanism for this connection by illustrating how equations emerged from real experiments, practical challenges, and human curiosity.

### 5.1 Research Questions

The study aims to explore four primary research questions:

- Influence of historical narratives on conceptual understanding
- Impact of storytelling on engagement and motivation
- Effects on students' ability to apply equations to real world problems
- Usability and adaptability of the packages for instructors

These aspects remain exploratory and will guide the design of instruments and data collection procedures.

### 5.2 Planned Study Context

The packages will be introduced in Fluid Mechanics, Thermodynamics, and Mechanics of Materials. The research team anticipates working with three to four instructors across multiple semesters to collect and assess the outcomes of the implementation, controlled with variations in course structures and pedagogical styles, among other factors. To ensure the framework supports a diverse student body and fosters a global engineering identity, the design philosophy explicitly includes a commitment to diverse representation. While foundational figures like Reynolds and Hooke are essential, future modules will feature a broader range of historical contributors to humanize the discipline for all students. This includes figures such as: Hypatia of Alexandria, early developments in fluid density. The Banū Mūsā brothers, 9th-century mechanical controls and hydrostatic principles.

### 5.3 Planned Data Collection Methods

The mixed methods approach integrates quantitative and qualitative data sources. Concept inventories will measure conceptual gains. To provide rigorous evidence of effectiveness, the study will utilize the following validated instruments, mapping HFP content directly to known "conceptual bottlenecks" as listed in Table 2. A sample assessment using the FMCI for The Reynolds "Battle of Forces" Challenge is shown in the appendix.

In addition, other assessment methods will be used. Student surveys will assess engagement and perceived relevance, reflective prompts will capture students' sensemaking processes, and faculty interviews will explore usability and scalability after implementation.

Qualitative data will be collected through reflective prompts embedded in classroom activities and semi-structured faculty interviews. The data will be analyzed using the thematic analysis framework established by Braun & Clarke [14]. This inductive approach allows for the systematic identification of emergent themes across different student cohorts.

Because this project is in the design phase and implementation begins in future semesters, the exact number of participating courses and students is not yet known. We anticipate that two sections of each course (approximately 40 students) will be involved in the study. Once data collection begins, quantitative analyses will include pre-/post-concept inventory comparisons using paired t-tests or ANOVA, depending on cohort structure, along with effect-size measures such as Cohen's d. Qualitative data will be analyzed using thematic analysis following Braun & Clarke. This mixed-methods approach will be fully detailed in future phases of the study.

Table 2. HFP mapping

| Course | Validated Instrument | Targeted Concept in HFP |
|---|---|---|
| Fluid Mechanics | Fluid Mechanics Concept Inventory (FMCI) [11] | Reynolds Number and Dynamic Similarity |
| Thermodynamics | Thermodynamics Concept Inventory (TCI) [12] | State vs. Path functions and the 2nd Law |
| Mechanics of Materials | Mechanics of Materials Concept Inventory (MCI) [13] | Stress-strain and Elasticity (Hooke) |

## 6. Anticipated Faculty Adoption and Usability

### *6.1 Implementation Tiers*

Engineering faculty often face significant time pressures and accreditation-driven content requirements. The packages are therefore designed to require minimal preparation time to facilitate seamless integration into existing lectures. To maximize usability, the HFPs offer three "tiers" of integration:

- The 5-Minute "Hook" (Engagement): Use the "Experimental Origin" and a historical image at the start of a lecture to ground the equation in a real-world failure.
- The 15-Minute "Concept Break": Facilitate a mid-lecture discussion, such as the "Life of Low Reynolds Number", to pivot from calculation to physical intuition.
- The Flipped Classroom (Asynchronous): Assign the "Historical Context" as a pre-lecture reading, using the "Classroom Activities" to drive in-person problem-solving.

### *6.2 Benefits and Challenges*

Instructors may find that the packages help address misconceptions, spark discussion, and support ABET outcomes related to communication and contextual understanding. The narratives may also help them engage students who benefit from contextual or story driven learning. Potential challenges include concerns about time constraints, uncertainty about presenting historical material, questions about student receptiveness, and effectiveness in advancing course educational objectives. These challenges will guide the development of implementation guides, support materials, and communication of systematic assessment outcomes and analysis.

### *6.3 Planned Evaluation of Usability*

Usability will be evaluated through interviews, classroom observations, and instructor reflection logs. These data will inform iterative refinement of the packages.

## 7. Discussion

The Historical Figure Package framework is designed to transform foundational engineering courses from a series of abstract mathematical hurdles into a narrative of human discovery. Instructors looking to adopt this framework should consider the following key lessons:

- Targeting "Threshold Concepts": HFPs are most effective when applied to "conceptual bottlenecks", topics such as the Reynolds number or the Second Law of Thermodynamics, where students otherwise only gain procedural proficiency without physical intuition.
- Humanizing the Inquiry: By framing equations as the outcomes of student struggle and experimentation (e.g., Reynolds' dye experiments), instructors can reduce the misconception that engineering knowledge is static or finalized.
- Flexible, Low-Stakes Integration: To overcome time constraints, faculty can utilize "Implementation Tiers," starting with a 5-minute historical "hook" to ground a lecture

before moving to more intensive 15-minute conceptual discussions or flipped-classroom activities.
- Evidence-Based Assessment: Utilizing validated instruments such as the Fluid Mechanics Concept Inventory (FMCI) or Thermodynamics Concept Inventory (TCI) allows faculty to move beyond exam scores and directly measure improvements in student conceptual reasoning.
- Fostering Inclusive Identity: Moving beyond the standard historical canon to include diverse figures like Emily Warren Roebling or the Banū Mūsā brothers. These broadening of historical figures beyond the canonical and commonly cited helps a more diverse range of students see themselves within the engineering profession.

## 8. Conclusion and Future Work

This paper presents a modular pedagogical framework, Historical Figure Packages, designed to integrate historical context, experimental origins, and conceptual narratives into core engineering courses. By reconnecting foundational equations with the people, experiments, and reasoning that produced them, the framework aims to support deeper conceptual understanding while maintaining technical rigor. At the time of writing, no classroom implementation or data collection occurred. Accordingly, this paper is presented as a Work-in-Progress focused on framework development and study design rather than learning outcomes.

At this time, the authors do not have the plan to release the HFP materials as a textbook or open education resource. The near-term goal is to work with a selected group of faculty adopters, collect feedback, and refine the materials as part of a multi-year implementation study.

Future phases of this project will focus on systematic assessment of student learning and engagement using mixed methods approaches, including concept inventories, analysis of student work, and reflective feedback. Additional efforts will expand the library of Historical Figure Packages across multiple engineering disciplines and refine instructor support materials to further reduce adoption barriers. Together, these steps will enable a transition from a design-focused study to a data-driven evaluation of the framework's educational impact and scalability.

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## Appendix Classroom Activity: The Reynolds "Battle of Forces" Challenge

**Learning Objective:** Students will move beyond the definition of Reynolds Number, to appreciate the dynamic interplay between inertia and viscous forces in fluid motion and apply the concept of dynamic similarity to scale-model testing.

**Part 1: The Historical Prompt (The "Hook")**
In the 1880s, Osborne Reynolds was obsessed with why pipes sometimes burst and why ships moved inefficiently. He realized that fluid motion was not just about speed; it was a "competition" between two properties: the fluid's desire to keep moving (Inertia) and its internal "stickiness" that tries to keep it orderly (Viscosity).

**Part 2: The Concept Inventory-Style Question**
This multiple-choice question is designed to test conceptual reasoning rather than rote calculation.

Scenario: You are an engineer designing a new high-speed underwater drone. Before building the full-scale 10-meter drone, you can test a 1/10 scale model in a water tunnel.

Question: According to Reynolds principle of Dynamic Similarity, if you want the flow dynamics around the scale model to be identical to the full-scale drone moving at 10 m/s, how fast must the water in your test tunnel move? Assume the water temperature and density are the same in both cases.

A) 1 m/s (The velocity should scale down with the size).
B) 10 m/s (The velocity should remain the same).
C) 100 m/s (The velocity must increase to compensate for the smaller size).
D) The velocity does not matter as long as the fluid is water.

**Part 3: The "Conceptual Bridge" (The Answer & Insight)**

Correct Answer: C (100 m/s)

The Historical Explanation: To have the "same flow dynamics," the Reynolds Number $Re$Re be equal for both the model and the prototype drone.

- Full Scale: $Re = \rho(10) \cdot (10)/\mu$
- 1/10 Scale Model: $Re = \rho(u)(1)/\mu$

If the length $L$ is divided by 10, the velocity $u$ must be multiplied by 10 to keep the Reynolds number constant. This is the "Aha!" moment Reynolds had: size and speed are interchangeable in the eyes of a fluid.

**Part 4: Assessment**

How this activity maps to HFP framework:

| FMCI Question Theme | HFP Narrative Component | Conceptual Gain |
|---|---|---|
| Scaling & Similarity | Dynamic Similarity | Students stop seeing *Re* as just a number and start seeing it as a metric of competing forces that underlies the methodology for effective scale-model testing. |