# Asynchronous, virtual teaching of physical experiments in hydraulics: a paradigm in practice

**Marios Valavanides**
University of West Attica, Greece and Hellenic Open University, Greece

**Abstract**

This paper presents the development and implementation of an innovative educational approach for teaching hydraulic experiments remotely, addressing challenges posed by equipment limitations, distance learning (DL), and exceptional circumstances like pandemics or exclusion. A case study is presented, focusing on an e-textbook created for asynchronous, virtual teaching of hydraulic experiments. The e-textbook features multimedia content, including videos and photos of 18 typical hydraulic phenomena, along with theoretical analysis, exercise instructions, and measurement tools.
The e-textbook is designed to support undergraduate civil engineering students studying fluid mechanics and hydraulics, combining theoretical and hands-on learning. It allows students to observe and analyze hydraulic phenomena remotely, improving their understanding of complex engineering problems and motivating further research. The material is structured into four main parts, covering foundational knowledge and key topics in hydrostatics, pressure hydraulics, and free surface hydraulics.
The multimedia content was produced using the infrastructure of the Hydraulics Laboratory at the University of West Attica and was successfully used during the COVID-19 pandemic when in-person labs were unavailable. The project was supported by a national grant and continues to serve as the primary textbook for the "Experimental Hydraulics" course, complementing other courses in fluid mechanics and hydraulics. In summary, the initiative modernizes hydraulic engineering education by integrating digital tools to enhance remote learning, ensuring continuity in education during disruptions like the pandemic.

**Keywords:** distance learning, asynchronous teaching, hydraulics laboratory.

## 1. Introduction and State-of the-art

The conventional approach to educating students typically involves in-class presentations of subject matter, analysis and solution of standard problems, and overviews of applications and paradigms. This “theory” approach generally relies on in-class delivery of material, utilizing a range of teaching aids such as blackboards, whiteboards, interactive monitors, or projectors. However, conducting physical experiments in a laboratory setting offers significant advantages, particularly for engineering and technology subjects. These benefits include hands-on experience in analyzing and observing physical models, taking measurements, understanding length and time scales, and gaining a tangible, three-dimensional perspective.

Unfortunately, access to laboratory resources is not always feasible. Factors such as limited budgets, resource constraints, distance learning (DL) setups, or extraordinary situations like pandemics, major outages, or other catastrophic events can limit or prevent lab access. Furthermore, students with physical disabilities may face additional challenges in accessing traditional lab settings. Holmberg and Bakshi (1982) highlight the critical role of laboratory work, discussing the strengths and limitations of both conventional and home-study lab activities. They also explore five alternatives to traditional labs and identify three areas needing improvement for effective distance lab experiences, based on the technology available in the 1980s.

A viable solution to these limitations is the development of asynchronous, virtual educational materials for lab experiments, such as multimedia repositories or e-textbooks. Two landmark resources in creating visual educational materials for fluid mechanics merit special mention.

The first, Illustrated Experiments in Fluid Mechanics: The NCFMF Book of Film Notes by Ascher Shapiro, published in 1972, is a classic work developed by the National Committee for Fluid Mechanics Films (NCFMF) with support from the National Science Foundation. Created to accompany a series of educational films produced at MIT, the book offers a rich, visual exploration of fluid mechanics concepts. Shapiro’s guide presents experiments that demonstrate key fluid mechanics phenomena with explanations, diagrams, and photographic sequences of principles like flow visualization, vorticity, laminar and turbulent flows, and boundary layers. By combining theoretical discussions with visual examples, this tool has been instrumental in helping students bridge the gap between abstract equations and observable flow phenomena.

The second resource, An Album of Fluid Motion by Milton Van Dyke (1982), captures the aesthetic and scientific beauty of fluid dynamics through a collection of high-quality photographs. The book presents a broad spectrum of fluid mechanics phenomena—laminar and turbulent flows, boundary layers, shock waves, and vortices—accompanied by minimal text to allow the images to communicate concepts on their own. Van Dyke’s album serves as an invaluable educational tool, revealing theoretical insights through direct observation and inspiring students and researchers with visually accessible representations of complex dynamics.

While these works offer comprehensive and visually engaging presentations of fluid mechanics principles, they cannot substitute laboratory exercises. Students cannot interact with these resources to take measurements or directly engage with the content, as they might in a lab.

Another paradigm for laboratory activity in DL is presented by Santiago *et al.* (2022) who introduce students to wastewater treatment using an advanced oxidation process.

In our case study, we present the development of an e-textbook for asynchronous learning of hydraulic experiments in a DL setting. This e-textbook features video-recorded laboratory experiments in hydraulics, presenting 18 typical hydraulic phenomena alongside theoretical analyses and exercise instructions. The content is accessible through hyperlinks, allowing students to observe phenomena, take measurements on their screens, and analyze data to understand physical properties.

The goal of this e-textbook is to provide an alternative, virtual laboratory experience. By integrating theoretical explanations with multimedia content—including videos and photographs of real experiments—the e-textbook offers a virtual approximation of in-lab activities. This format enables students to engage with hydraulic experiments, make measurements, and analyze collected data as though they were physically present in the lab.

## 2. History and implementation

Between 2010 and 2015, multimedia content was created at the Hydraulics Lab of the Technological Educational Institute of Athens (TEI Athens), a higher education institution that later merged with the TEI of Piraeus to form the University of West Attica in 2018. The four-year curriculum offered by the Department of Civil Infrastructure Engineering (CIE) at TEI Athens combined theoretical and laboratory-based instruction. Generally, each four-hour weekly theory class was supported by a two-hour laboratory session, which involved small projects where students observed, measured, and analyzed relevant phenomena. Following a major refurbishment, the Hydraulics Lab was fully operational, and students, organized in small groups of 6–8, participated in these two-hour weekly lab sessions across several hydraulics courses (see Figure 1).

Figure 1: Physical lab sessions at CIE/TEI Athens.

To expand lab access through electronic classes (e-class), key experiments, particularly those that allowed for visual observation and video documentation, were recorded. This initiative was part of the project "Open Academic Courses at TEI Athens," funded by the European Union's (EU) European Social Fund (ESF) and national resources under the Operational Program "Education and Life-Long Learning." This project aimed to develop open and distance-access course material. As part of this initiative, the lab materials were restructured into "exercise packages" that combined fundamental theoretical analyses with multimedia content (photos and videos), charts, and guidelines for data measurement, analysis, and calculations of key hydraulic variables, along with interpretative notes for student observations.

During the COVID-19 restrictions from 2020 to 2022, online courses were the only viable option to sustain educational activities, which posed significant challenges for lab-based courses. However, as multimedia materials were already organized in exercise packages, the "*Experimental Hydraulics*" course (course code CE0843 in the five-year Civil Engineering curriculum, https://civ.uniwa.gr/en/courses/undergraduate/) was adapted for remote learning. Students could observe actual hydraulic phenomena through videos and take measurements on their home monitors. This adaptation worked smoothly, requiring only minor editorial adjustments to the packages. Both instruction and assessment (exams) were conducted through a mix of synchronous and asynchronous methods.

In the post-COVID period (2021–2023), the multimedia materials were further refined and compiled into an e-textbook, with support from the Kallipos+ project. The e-textbook is currently undergoing final proofing to ensure editorial consistency and compliance with the Kallipos+ project book series standards.

It is noteworthy that, following the merger of TEI Athens and TEI Piraeus to form the University of West Attica, the Hydraulics Lab at TEI Athens was dismantled, transported, and reassembled at a new location on

Campus 2 (Ancient Olive Grove), which temporarily halted physical lab operations until early 2024. However, the "*Experimental Hydraulics*" course continued uninterrupted in the same distance-learning format. Since mid-2024, the e-textbook has been enriched with new exercise packages as additional lab equipment is installed (see Figure 2).

Figure 2: Laboratory reproduction of hydraulic phenomena along a six-meter flume at the new Hydraulics Lab, Campus 2. These sessions support theoretical instruction by illustrating fundamental concepts in open-channel flow.

## 3. The e-textbook

The e-textbook (Figure 3) is organized into four main parts, comprising 21 chapters in total. Part 1 covers foundational knowledge and methodological tools essential for designing and conducting experiments, including dimensional analysis, metrology, and curve fitting. Parts 2 through 4 are devoted to Hydrostatics (Part 2), Pressure Hydraulics (Part 3), and Free Surface Flow Hydraulics (Part 4). Each chapter represents a laboratory exercise or “lab work package” that includes theoretical analysis, multimedia materials (videos, photos, illustrations), step-by-step instructions for conducting the lab exercise, guidance on measurement-taking, pre-formatted data tables, calculations of key hydraulic variables, and prompts for reflection, conclusions, and practical insights. In the following we will present a selection of lab exercises:


Figure 3: The cover page of the e-text book.

Lab Exercise 3.2 involves using the classical free-sinking ball method to evaluate the viscosity of thick liquids (see Figure 4, http://users.uniwa.gr/marval/HydroLab/v0502_Stokes_4balls.mp4). Students observe steel balls of various diameters sinking freely in different liquids (e.g., machine oil, glycerine, liquid soap) and, using the ruler and timer visible in the video, record position and time measurements directly on their screens. They plot these measurements, apply least-squares fitting to determine the sinking velocity, and calculate the fluid's viscosity using Stokes' law.

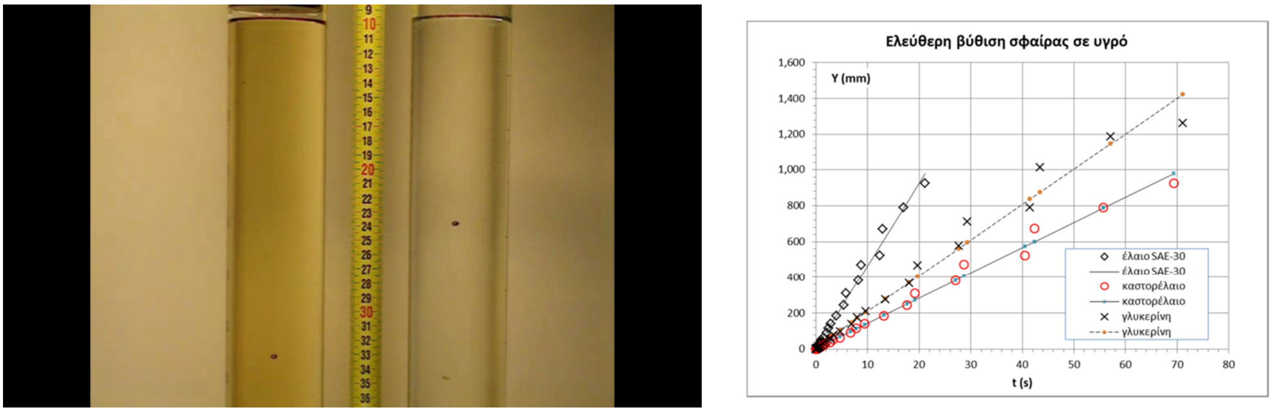


Figure 4: The free-sinking ball experiment. Left: video example. Right: typical measurements of ball velocities in various viscous liquids, with least-squares fitting applied.


Figure 5: Experimental setups for measuring surface wave celerity at different water depths (left: 18 mm, right: 75 mm).

Lab Exercise 4.4 explores the basic phenomenology of shallow water waves, providing videos for students to calculate wave propagation velocity (celerity). Figure 5 illustrates experiments for two water depths, one for 18 mm (http://users.uniwa.gr/marval/HydroLab/v1402_Celerity_y018mmC.mp4) and the other for 75 mm, (http://users.uniwa.gr/marval/HydroLab/v1402_Celerity_y075mmC.mp4), in a 6-meter-long flume. Using a stopwatch or video timer, students measure the time a wave travels a 5-meter distance, indicated by two white bands.

Lab Exercise 4.5 demonstrates hydraulic jump phenomenology in flumes of different dimensions. In Figure 6, students observe how a hydraulic jump's position can be controlled upstream, e.g. by adjusting a sluice gate (http://users.uniwa.gr/marval/HydroLab/v1501_HydraulicJump_UpstrContrC.mp4) or downstream, e.g. by a weir (http://users.uniwa.gr/marval/HydroLab/v1502_F6m_HydrJump_DwnstrQContrC_480.mp4) by changing its height. Students measure pre- and post-jump depths to estimate flowrate and hydraulic energy loss, and create charts comparing hydraulic jump characteristics.

Lab Exercise 4.6 covers flow past a sluice gate (Figure 7). Students observe flow structure and measure flow characteristics (http://users.uniwa.gr/marval/HydroLab/v1601_sluicegate_jumpC.mp4) with rulers mounted on the flume wall. The support video, on the right, provides a visualization of flow lines, (http://users.uniwa.gr/marval/HydroLab/v1602_streaklines_sluicegate.mp4) allowing students to verify that sluice gate flow results in minimal hydraulic energy loss.

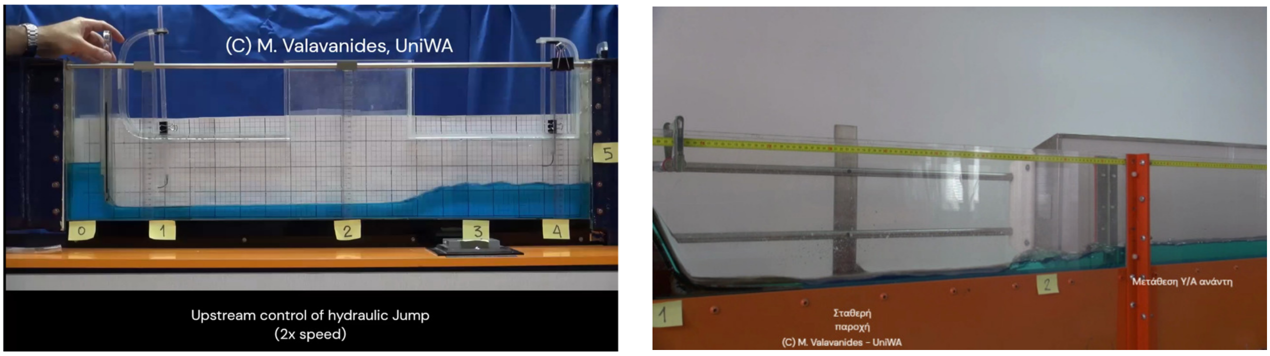


Figure 6: Studying hydraulic jumps in different flume setups. Control via upstream sluice gate and downstream weir.

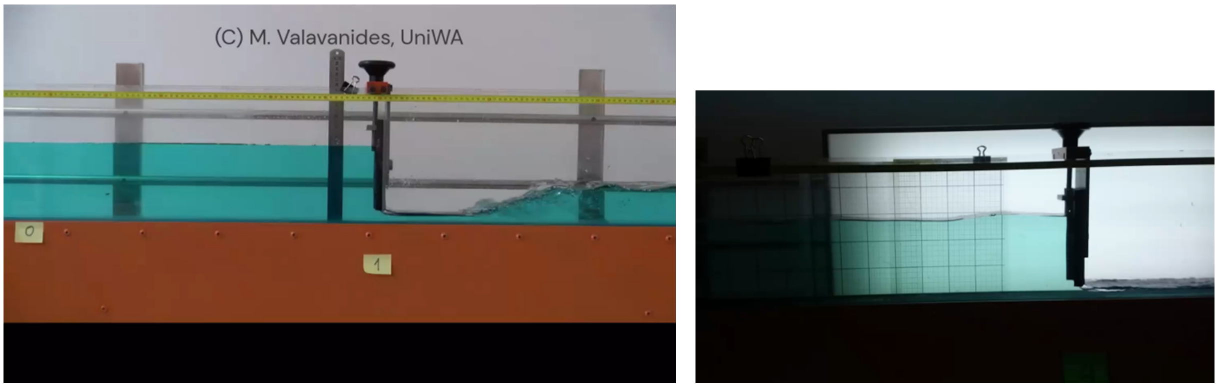


Figure 7: Flow past a sluice gate and formation of hydraulic jump. Left: video appropriate for taking measurements. Right: flow line visualization to confirm minimal energy loss.

Lab Exercise 4.10 presents flow over a smooth-crested weir (Figure 8). Students examine the flow structure and measure various geometric characteristics using rulers as indicated on the video on the left (http://users.uniwa.gr/marval/HydroLab/v1901_SmoothWeir_JumpC.mp4). The video on the right (http://users.uniwa.gr/marval/HydroLab/v1903_streaklines_smoothweir_MOV_0579.mp4) includes flow line visualization, highlighting hydraulic energy loss across the weir.

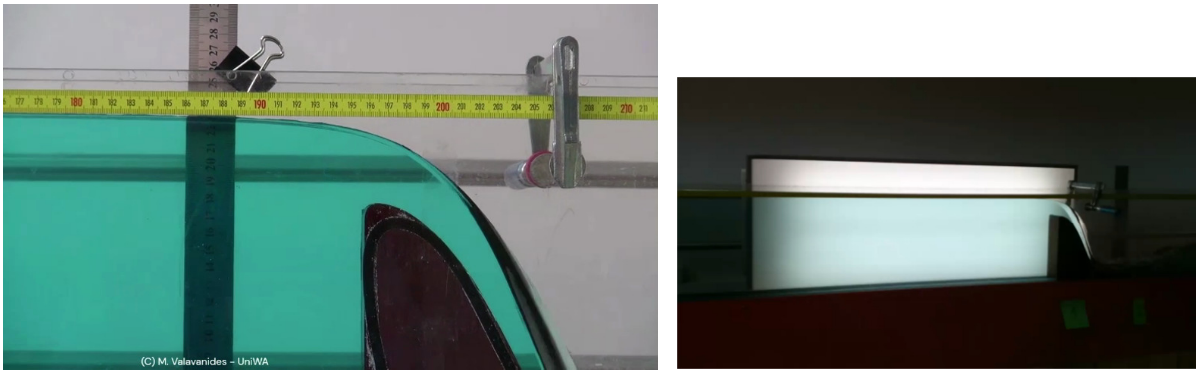


Figure 8: Flow over a smooth crested weir. Left: video appropriate for measurements. Right: flow line visualization to indicate energy loss.

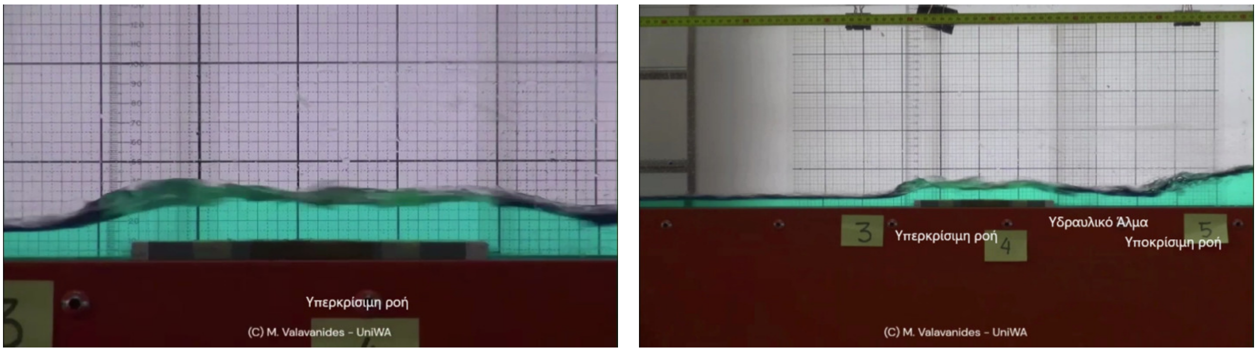


Figure 9: Flow over a bed bump. Taking of measurements is possible using the ruler and the backround orthogonal frame grid. Left: snapshot showing supercritical flow. Right: snapshot showing the transformation of supercritical flow into subcritical flow resulting in a hydraulic jump.

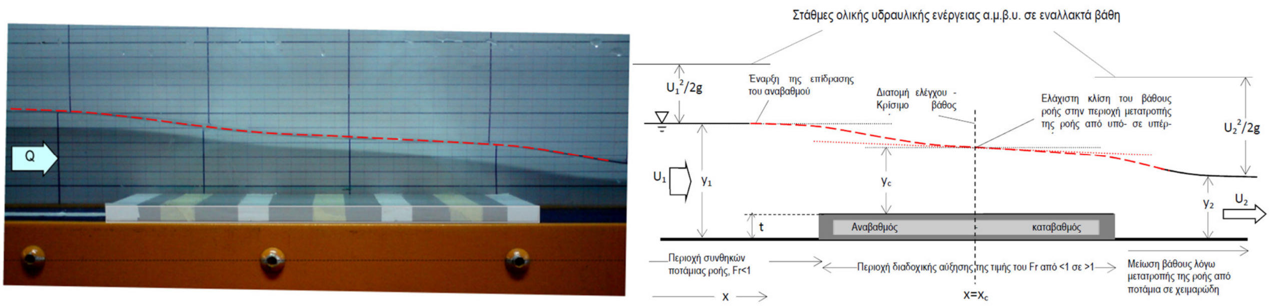


Figure 10: Flow over a bed bump. Left: snapshot appropriate for measurements. Right: geometric analysis of the flow structure at the left.

Lab Exercise 4.11 examines flow over a short bed bump (bump-flow), with videos capturing both supercritical flow and the transition from super- to subcritical flow with a mild hydraulic jump, see Figure 9 (http://users.uniwa.gr/marval/HydroLab/v2004_sharpbump_sub_sup_jumpComsdr.mp4). Students take measurements from snapshots (Figure 10) and apply geometric analysis to estimate the flowrate.

More videos or available at the web page of the Hydraulics Lab, Dept. of Civil Engineering, University of West Attica (http://users.uniwa.gr/marval/HydroLab/index_en.html)

## 4. Conclusions

The development and implementation of digital educational material compatible with distance learning (DL) frameworks enables asynchronous, virtual teaching of hydraulic experiments. This educational resource, an e-textbook, integrates video-recorded laboratory experiments in hydraulics, along with theoretical analyses and step-by-step exercise instructions. The e-textbook's innovation lies in offering students direct access to multimedia content that allows them to observe hydraulic phenomena, take measurements directly on their screens, and analyze these measurements to deepen their understanding of the physical principles involved. All multimedia content can be accessed via hyperlinks for easy download.

Designed for use in undergraduate civil engineering programs, the e-textbook supports both in-class and DL teaching in fluid mechanics and hydraulics. Its objective is to enhance students' skills in addressing hydraulic engineering challenges by blending theoretical concepts with empirical, hands-on learning. The multimedia content also boosts students' engagement, encouraging interest in research and advanced studies. Moreover, it enables students to critically evaluate real-world hydraulic phenomena, empowering them to form well-reasoned conclusions when managing, operating, or redesigning hydraulic systems.

The e-textbook's digital format, combined with detailed theoretical analysis, provides an accessible, effective alternative to hands-on lab work. This approach enables remote laboratory practice in cases where lab equipment is unavailable, allowing students to prepare thoroughly and perform actual experiments more effectively when resources are available. Additionally, it enhances the efficiency of training by enabling more complex project work.

The multimedia material was produced with the infrastructure of the Hydraulics Laboratory at the University of West Attica, finalized before the lab's relocation and the onset of the COVID-19 pandemic. During the pandemic restrictions, the "*Experimental Hydraulics*" course transitioned to an online DL format, using this multimedia material for the first time as a "virtual realization" of laboratory exercises. Students could remotely observe hydraulic phenomena through video and take measurements from their screens, ensuring continuity of practical learning despite physical limitations.

This initiative modernizes hydraulic engineering education by leveraging digital tools to enrich learning and maintain educational consistency. In recent years, particularly post-COVID, the e-textbook has served as the primary textbook for the course "Experimental Hydraulics" and a supplementary reference for courses in fluid mechanics and hydraulics.

The e-textbook aims to:

- Enhance students' ability to tackle hydraulic engineering problems through a blend of theoretical and empirical training.
- Help students critically analyze field-observed hydraulic phenomena and draw substantiated conclusions, particularly regarding hydraulic system operation, management, or redesign.
- Spark educational interest and motivate students to pursue research projects in postgraduate studies.

As complementary study material, this e-textbook provides significant advantages. When lab resources are accessible, it prepares students to manage in-person experiments effectively or undertake complex projects, thus improving training outcomes. In situations lacking lab equipment, it facilitates effective remote DL education, ensuring students continue to develop key skills.

## 5. Aknowledgements

The author would like to thank the Hellenic Open University and the Univeristy of West Attica for co-supporting publication of this work. The support from Kallipos+ in deriving the e-textbook is greatly acknowledged.

## 6. References

Holmberg, R.G., Trilochan S. Bakshi, T.S. (1982) Laboratory work in distance education. *Distance Education* **3**(2), 198-206

Hsiung, S. C., Ritz, J. (2014). Teaching laboratory courses using distance learning technologies. *Journal of Engineering Technology* **31**(1), 18-25

Santiago, D.E., Melián, E. P., Reboso, J.V. (2022) Lab at home in distance learning: A case study. *Education for Chemical Engineers* **40**, 37-44, https://doi.org/10.1016/j.ece.2022.05.001

Shapiro, A. (1972) "*Illustrated Experiments in Fluid Mechanics: The NCFMF Book of Film Notes*", NSF, Educational Development Center, MIT publications, http://web.mit.edu/hml/ncfmf.html

Valavanides, M. (2024) *Experimental Hydraulics- Lab reproduction and analysis of hydraulic phenomena* , e-textbook, 2024, Open Academic Electronic Textbooks, Kallipos+, Ref. 60020100, (final proofing stage)

Van Dyke, M. (1982) "*An Album of Fluid Motion*" The Parabolic Press. Stanford California, ISBN 0-915760-02-9, http://courses.washington.edu/me431/handouts/Album-Fluid-Motion-Van-Dyke.pdf , retrieved 12/9/2023