2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39357

Work-in-Progress: Hands-on group activities for large fluid mechanics classes in a traditional lecture hall setting

Dr. Fiona C. Levey, Worcester Polytechnic Institute

Dr. Fiona Levey is an Associate Teaching Professor the Department of Mechanical and Materials Engineering at Worcester Polytechnic Institute. She teaches materials science and thermal fluids classes and advises capstone design projects. She employs active learning and project-based learning in her curriculum, using varied approaches for different levels, and correlating course design and teaching techniques to learning outcomes. Dr. Levey was awarded Best Professional Paper at the ASEE NE conference in 2020 for collaborative research related to identifying and addressing gaps in Math skills needed for courses at the sophomore level. She draws from her cross-functional team experience as a Metallurgical Engineer in applied research and development prior to moving into academia.

Work-in-Progress: Hands-on group activities for large Fluid Mechanics classes in a traditional lecture hall setting

Abstract

Hands-on learning has been shown to improve student learning outcomes, but it is challenging to incorporate this into large lecture-style classes. It is possible to introduce a hands-on component into a traditional lecture-style course by adjusting the schedule to include a regular lengthy lab-style component. However, in addition to the logistical issues of space and room scheduling constraints, students have reported feeling overwhelmed by full academic schedules and increased workload. Furthermore, the mental health crisis amongst youth and young adults has revealed feelings of isolation that were present prior to Covid and were exacerbated during the pandemic. To address these issues, I have developed activities for groups of 3 in a 90-student offering of fluid mechanics that intentionally foster connections between students. The course is an introduction to the topic and is taught mainly to junior level mechanical engineering students. This course material itself can be quite dry. These activities start with an in-class Stokes law experiment that utilizes easily transportable inexpensive materials that can be quickly distributed in class so that all 30 groups participate simultaneously. The experiment itself is well known, but the physical set-up used in this work is intentionally designed to require group collaboration for the measurements. The prompts are open-ended, so that continued teamwork is needed for the interpretation, analysis and presentation of the results. The experiment is conducted in the lecture hall during 15-20 minutes of regular class time, with additional group work using shared documents occurring outside of class hours, culminating in a written report. Subsequent group activities that encompass multiple other topics in the course are based on this initial experiment. By weaving this through the course, groups work collaboratively on topics such as viscosity, buoyancy, flow regimes, drag, creeping flows and experimental analysis. This paper describes these activities and the associated materials needed for the initial experiment. The effectiveness of this new course module on forging connections and increasing student learning and engagement will be gauged using the Student Assessment of Learning Gains (SALG) instrument in my spring 2023 offering of the course and preliminary results will be available in June.

Introduction and Pedagogical Context

While the advantage of hands-on learning is well established [1], educational needs have changed in many ways over the past few years. This is partly due to Covid isolation and its ripple effects, and partly due to a rapidly evolving broader context for how people socialize and access, distribute and retain information. A forty-year study from 1976-2017 showed increased levels of loneliness and isolation in the 2010's was strongly correlated with fewer in-person interactions [2]. Prior to the pandemic a significant portion of college students reported feeling lonely [3]. Students have a deep need for connection [3], which is more pressing in light of the Mental Health crisis in the United States which was exacerbated by Covid isolation [4]. College students have also reported feeling overwhelmed by academic stressors, which include demands on their time [5]. The adverse effects of loneliness are not limited to schools and colleges. One study found that “lonely employees cost workplaces an estimated $4000+ per year (per employee) in lost days of work” [6]. To further complicate matters, anecdotal observations by the author show student preference for closed form questions which mirrors the learning requirements for success on standardized tests, and many students are uncomfortable with ambiguity and open-endedness.

Educational resources within the higher education landscape are often constrained by space and faculty and student schedules. This makes it challenging to add a laboratory component to a large lecture-based class to give students opportunities to do hands-on experiments in small groups.

The combination of these factors has provided impetus for developing hands-on experiments that are inexpensive and easy to implement in a traditional lecture hall with 90 students, and take no more than 20 minutes of class time including set-up. The purpose of these activities are three-fold: a) give students opportunities to link theory and practice in a hands-on fashion; b) form connections amongst each other and c) keep the hands-on component of each activity within class time. With these constraints, the activities are designed for groups of 2-3 using a combination of materials that students already own and others that are easily obtainable and can be readily taken to class and distributed to 30-45 groups. Each experiment is designed so it relates to multiple course topics and can be used in corresponding assignments.

This paper describes one of these experiments and associated activities and details the materials needed, planned group and class logistics, and a broad description of the assignments created and discussions planned to relate course content to the experiment. While the experiment itself, measuring viscosity with a Stokes Law viscometer, is well documented, the pedagogical approach described in this paper has been designed to address a critical set of student needs related to learning and well-being. The effectiveness of this approach will be assessed in my March 2023 offering of the course, and preliminary results will be shared in June.

Experimental set-up

The stokes Law viscometer relates viscosity to terminal velocity, V_t, for a sphere of diameter D falling through a fluid, of density ρ and viscosity μ, in creeping flow conditions, where the Reynolds number, $Re \leq 1$. This typically occurs in situations where the particle is very small or the fluid is viscous, as can be inferred from

$$Re = \frac{\rho V D}{\mu}$$

When an object falls through a fluid at terminal velocity, acceleration = 0 and the weight of the object is balanced by the buoyant force and drag force on the object, or

$$W = F_B + F_D$$

The drag force exerted on an object as it moves through a fluid is function of the drag coefficient, F_D.

$$F_D = C_D \frac{1}{2} \rho A V^2$$

For a sphere, the frontal area *A* is the area of the circle, $\pi D^2/4$, and for creeping flow conditions the drag coefficient C_D of a sphere is *24/Re*, so the drag force would be

$$F_D = 3\pi\mu V D$$

which is Stokes law. The weight of a sphere and the buoyant force on a sphere are, respectively,

$$W = \rho_{sphere}\pi \frac{D^3}{6} g \text{ and } F_B = \rho_{fluid}\pi \frac{D^3}{6} g$$

Substituting into $W = F_B + F_D$ at terminal velocity we get

$$(\rho_{sphere} - \rho_{fluid})\pi \frac{D^3}{6} g = 3\pi\mu V_t D$$

or

$$\mu = \frac{g D^2 (\rho_{sphere} - \rho_{fluid})}{18 V_t}$$

Therefore, the viscosity of a fluid can be measured by determining the terminal velocity of a sphere moving through the fluid under creeping flow conditions.

A Stokes law viscometer consists of a tube with sufficient length to allow the sphere to achieve terminal velocity, a fluid with viscosity μ and density ρ, and a spherical object with diameter D. The fluid and sphere diameter should be chosen so that at terminal velocity $Re \leq 1$. A method of inserting the sphere centrally in the tube should also be considered so that the sphere moves through the fluid rather than sliding down the wall of the tube. Wall effects increase the drag force on the sphere, and these are a function of the ratio of ball diameter to tube diameter. Various correlations for the increased drag have been reported in the literature [7],[8],[9] and they converge for ratios of ≤ 0.1 [9].

The setup chosen for this class experiment consists of:

- 2 mm steel ball bearings, an average of two per group to allow for trial and error
- a 1” diameter 12” long clear plastic tube which is sealed at the bottom. This gives a sphere: tube diameter ratio of < 0.1
- a polypropylene plug to seal the top of the tube for ease of transport and storage prior to class
- food grade glycerin, 99.7% purity
- 12” ruler (brought to class by students)
- a video recording device used in slow motion (student’s phone)
- a clock in real time (a second student’s phone)
- optional: a funnel may be used to insert the ball bearing centrally; however, central placement by hand is also effective.

Thirty tubes are filled with glycerin and capped prior to class. The same quantity of glycerin is added to each tube and the mass of glycerin per tube is measured. Fifteen filled tubes are kept at room temperature and the other fifteen are refrigerated overnight. A set of 2 mm ball bearings is brought to class together with the capped tubes. (Additional 4 mm diameter and 8mm diameter ball bearings will also be brought to class and kept aside for enrichment activities as detailed in the discussion.)

At the start of class, students assemble into their predetermined groups of 3. One member collects a tube and a ball bearing (and a funnel if preferred), while the other two group members get the ruler, phones and recording space set up. The height of the glycerin in the tube is recorded prior to running the experiment.

To run the experiment, the lid is removed from the tube and then student A holds the ruler next to the tube and ensures that both are vertical, student B starts a slow motion well-focused phone video recording of the setup with a timer running on the screen of the second phone, then student C drops the ball bearing into the glycerin, taking care that it lands centrally in the tube. Student B stops the video recording after the ball bearing reaches the bottom of the tube. A picture of a trial run in progress is shown in Figure 1.

Figure 1: Trial run with a 2 mm ball bearing and a ½" tube

To wrap up, the ball bearing is left at the bottom of the tube, the polypropylene plug is fitted back onto the tube, ensuring a good seal, and the tube (and funnel if used) are returned to the front of class. Students A, B, and C co-ordinate whether they would like to do the group analysis in person or remotely. In either case, students need to analyze the data and write the report using a shared platform.

The estimated class time for this activity is 5 minutes to collect materials from the front of class and clarify instructions, 5-10 minutes to co-ordinate within the group and run the experiment, and 5 minutes to return the materials to the front of the class for a total of 15-20 minutes.

Student analysis of results

Students are tasked with creating a spreadsheet of distance travelled and time elapsed in small intervals and using these values to plot velocity vs time of the ball bearing moving through the glycerin and use this to determine the terminal velocity. Students will need to decide appropriate measurement intervals and how to best create the graph, which will require some engineering judgement and discussion as a group. Some students will not have used spreadsheets for open-ended analysis, so this will provide an opportunity to develop this useful skill.

A graph created by the instructor from a trial run with the prototype is shown in Figure 2. The first time reading was taken after the ball bearing had fallen 0.5 cm through the glycerin. Each velocity plotted was the average velocity over the preceding distance interval. The process of determining terminal velocity in this small distance required patience since the clock display recorded in slow motion showed increments of 0.04 – 0.05 second with intermediate times estimated by the relative intensity of the overlaid intervals.

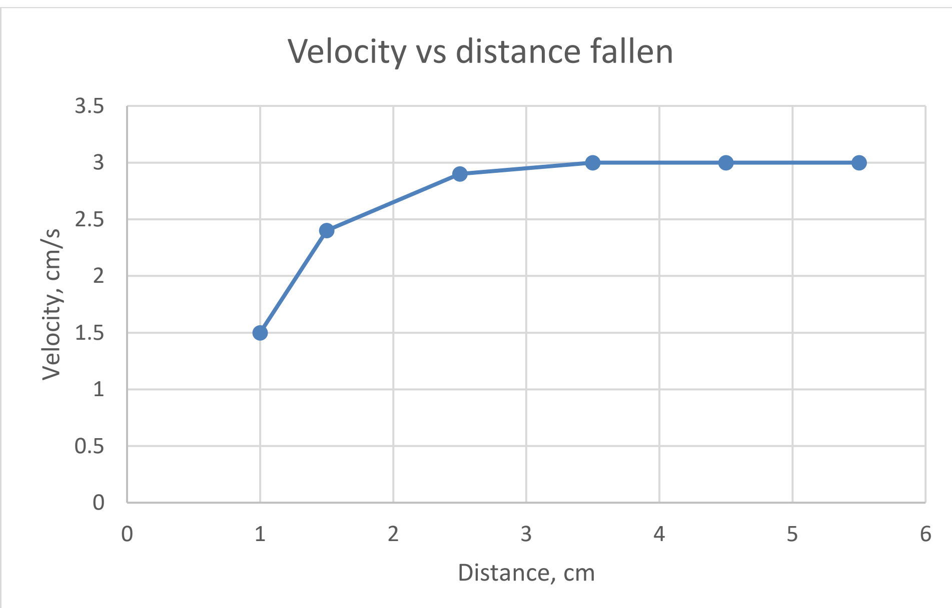

Figure 2: Plot of velocity vs time for a trial run with the prototype.

Students will be given the Stokes equation relating terminal velocity and viscosity and tasked with calculating the viscosity of the fluid in their tube and validating the use of the equation.

$$\mu = \frac{gD^2(\rho_{sphere} - \rho_{fluid})}{18V_t} \text{ which is valid when } \frac{\rho VD}{\mu} \leq 1$$

Groups will need to calculate the density of the glycerin using the mass supplied by the instructor and a volume calculation using the diameter of tube (provided) and their measured height of the glycerin in the tube. The density of steel can be obtained from an internet search.

Since half of the groups will be given cold glycerin, the other half glycerin at room temperature, the results should be significantly different. The day after the analysis is completed, the groups will enter their calculated viscosities into a live poll during class time and this will be used as the basis for a class discussion about temperature effects of viscosity and statistical variation. The accuracy of this method will be compared to more a sophisticated measurement method by measuring the viscosity of room temperature glycerin in class with a paddle viscometer (as a demonstration) and calculating the experimental error.

Relating this activity to other aspects of the course

This experiment will be related to buoyancy, drag, flow regimes, Stokes Law and experimental limitations at the appropriate points in the course. The two activities planned to encompass these topics are detailed below. Students will be given 10 minutes in class to work collaboratively in their groups.

A few days after the first activity, the same groups as before will calculate the buoyant force of the glycerin on the sphere and determine the effective weight of the ball bearing. This exercise will require the creation of a free body diagrams (FBD) which may be new to students who have not taken statics.

Towards the end of the course, external flow around objects includes the topics of creeping flow at Re<<1, drag around a sphere, and Stokes law. The student groups will be tasked at this point with deriving the equation they were given during their initial experiment. The correction factor needed to account for wall effects and rotational effects on drag will also be discussed at this point, using experimental correlations from literature [7], [8], [9].

Discussion

Student learning has been changing in an increasingly digital world. Additionally, students lost significant learning opportunities during the pandemic, both for technical skills and for soft skills such as group work. Increased isolation also worsened the mental health crisis amongst youth and young adults.

These activities are designed to address multiple learning outcomes: teamwork, becoming comfortable with some open-endedness in assignments, applying theory to practice and mastering technical skills such as use of spreadsheets and graphing tools. At the same time, the modules are structured to forge connections between students, increase student engagement through a lab-style activity and collaborative group work, and avoid adding to students' already full schedules.

An example of designing for team collaboration is the choice of materials. Providing a graduated cylinder would allow a single student to perform the experiment while other group members observed, whereas using a clear tube with a student-provided ruler would necessitate teamwork. The intentionally open-ended nature of the prompts will require groups to deliberate about the best course of action and choose a suitable method of analysis. Some students may inadvertently warm up one portion of the glycerin by holding one section of the tube which will cause a remarkable decrease in viscosity in that region of the fluid, and may lead to rich class discussion.

Another planning consideration is an anticipated spread in the rate of completion of the experiment. For groups that finish quickly, 4 mm ball bearings will be available to qualitatively compare the results between the larger and smaller ball bearings to gauge the effect of increasing diameter. A few measurements can be made to make rough quantitative comparisons. The 8 mm diameter ball bearings will have a ball to tube diameter ratio of 0.3, so groups with even more time on their hands will be encouraged to make another video that can be included in the class discussions during the last segment of the course related to rotational effects on drag and testing constraints related to wall effects.

The introduction of new course activities necessitates either cutting or replacing existing material in the syllabus. These three activities will take a total of 40 minutes of class time. Half of this time will directly replace traditional lecture time on the same topics, and some restructuring of the course will be required to make up the rest, with students reading up on theory in order to complete the report and assignments and prepare for class discussions, rather than passive learning in lecture.

The initial set-up cost of a set of 30 experiments is under $200, as detailed in Figure 3. Glycerin has a shelf life of 2 years; the other materials can be reused in many years of subsequent course offerings. The filled tubes can be easily stored and transported to class in an 8”X8”X14” box. A rare earth magnet can be used to remove the ball bearings from the tubes for cleaning and storage.

Material (shipping and taxes included)	**Manufacturer**	**Part number**	**Cost, $**
50 X 1” diameter PETG 1” X 12.125” tube with sealed bottom & polypropylene round plug	ClearTec	SKU: SBT00170 &PRP1.000RED	112
Ball bearings, variety pack 2-8 mm diameter, chrome steel, 20-80 per size	Hilitchi	ASIN: B07VNSDLWS	17
Glycerin, 2 X 1 gallon food grade, minimum 99.7% purity	Duda energy	ASIN: B0095P90AM	66
Ergonomic rare earth magnet for removing ball bearings, set of 2 (optional)	Macgreen	ASIN: MCH2	(13)
Mini funnels, 50 per pack (optional)	TailaiMei	ASIN: B07H5C4SNX	(7)
Total			**195-215**

Figure 3: Cost of materials for 30 Stokes law viscometer sets.

This activity can be expanded to include a variety of fluids with each group predicting the fluid they were given from their viscosity calculation. This would necessitate that each group weigh their tube at the start of the experiment rather than being told the mass of the liquid. The feasibility of adding this level of complexity will be determined early in the course based on students' background in the foundational courses.

Impact on student learning and teamwork will be assessed with the Student Assessment of Learning Gains SALG instrument during the Spring 2023 offering of the course. Preliminary results will be shared at the conference in June.

References

1. S. Freeman, "Active Learning Increases Student Performance in Science, Engineering, and Mathematics," in *National Academy of Sciences*, vol. 111, no. 23, pp. 8410-8415, 2014.

2. J.M. Twenge, B.H. Spitzberg and W.K. Campbell, "Less in-person social interaction with peers among U.S. adolescents in the 21st century and links to loneliness," in *Journal of Social and Personal Relationships*, vol. 36, no. 6, pp 1892-1913, 2019.

3. J. Martino, J. Pegg and E.P. Frates, "The Connection Prescription: Using the Power of Social Interactions and the Deep Desire for Connectedness to Empower Health and Wellness," in *Am. J. Lifestyle Med.*, vol. 11, no. 6, pp 466-475, Oct. 2015. doi: 10.1177/1559827615608788. PMID: 30202372; PMCID: PMC6125010.

4. Z. Abrams, "Student mental health is in crisis. Campuses are rethinking their approach," *Monitor on Psychology*, APA, vol. 53, no. 7, October 2022, accessed 12 Feb. 2023, available at https://www.apa.org/monitor/2022/10/mental-health-campus-care.

5. G. Barbayannis et al, "Academic Stress and Mental Well-Being in College Students: Correlations, Affected Groups, and COVID-19," in *Front. Psychol.*, vol. 13, no. 886344, May 2022. doi: 10.3389/fpsyg.2022.886344. PMID: 35677139; PMCID: PMC9169886.

6. J. Gifford, "The hidden cost of loneliness in the workplace", *projectconnect-us.com*, blog no. 56, accessed 25 Feb. 2023, available at https://projectconnect-us.com/blog/collaborate.

7. A.W. Francis, "Wall Effect in Falling Ball Method for Viscosity," in *Physics*, vol. 4, pp. 403-406, Nov 1933.

8. A. Ambari, B. Gauthier-Manuel and E. Guyon, "Direct measurement of tube wall effect on the Stokes force," in *Phys. Fluids*, vol. 28, no. 5, pp. 1559-1561, May 1985.

9. M. Iwaoka and T. Ishii, "Experimental wall correction factors of single solid spheres in circular cylinders," in *Journal of Chemical Engineering of Japan*, vol. 12, no. 3, pp. 239-241, 1979.