Hands-on Engineering Homework: A New Approach to Out-of-Class Learning

Alfred J. Bedard, Jr.; David G. Meyer
University of Colorado at Boulder

Abstract

Our goal is to develop a new way to provide experimental complements to theoretical courses, creating suites of simple experiments that can be done at home and assigned like homework problems. Such simple, but elegant experiments we call hands-on-homeworks (HOH) and these will:

- encourage students to use engineering theory to explain everyday phenomena and compare their observations to theoretical predictions,
- provide open-ended opportunities to explore engineering questions using readily available materials and familiar experiences,
- train students to conduct "reality checks" and naturally apply theoretical analysis to experimental observations, and
- provide continuous opportunities for students to empirically explore engineering questions throughout their college careers and develop habits contributing to life long learning.

Thus far, we have designed and piloted 15 HOH with an additional eight in progress and 24 in planning stages. Typically, these consist of a theory problem statement which includes a HOH component. Many of these HOH also include a classroom demonstration, and a more quantitative closure experiment. We will present examples of HOH created to date and review plans for testing and evaluation.

Introduction

Background

There have been various approaches to the challenge of providing experimental components to theoretical courses. For example, groups of formal experiments have been provided to give concurrent or added enhancements to analytical subject matter. Alternatively, complete experimental courses have been added to curricula. We take a new approach in the context of the new Integrated Teaching and Learning Laboratory (ITLL) now under construction at the University of Colorado at Boulder. Our new approach, which we call hands-on-homework (HOH), will be an integral component of the enhanced undergraduate curriculum changes planned and will make use of ITLL resources.

In the past, valuable resources have been created for providing exercises, puzzles, and mysteries drawing on day-to-day experiences to challenge and encourage further exploration. However, typically there is little or no tie in to theoretically obtained results.

We plan hands-on verification of a range of physical phenomena, emphasizing close coupling between analytically obtained relationships and simple experiments. Instead of separating theory and experience (either in time or space), we envision a close integration; so that students will obtain an immediate confrontation between analysis and reality — leading to the natural exploration and questioning that occurs when theory and experiment do not agree. Specifically, we are developing a set of simple, but elegant experiments, that are essential components of analytical problems. We provide several examples in this paper, but plan to produce an extensive set of hands-on homework problems covering basic disciplines.

We envision the following areas of application:

1. Purely analytical results obtained from solving, for example, Navier-Stokes equations will yield an expression that may be verified by a simple experiment (a "kitchen sink" experiment — one that could be done at home with a minimum of hardware).

2. Dimensional reasoning will yield a group of dimensionless numbers, but it often will not be clear how these quantities should be combined in a way that makes sense physically. Again, simple experiments can guide combining dimensionless groups so that physically meaningful relationships between complex quantities are obtained.

3. Numerical results can be especially convincing when intriguing visualizations of processes are obtained. Students should be imbued with the realization that all results should be questioned and that sometimes clear guidelines can be obtained using simple experiments.

We have all probably been in the position of obtaining a result from analysis and feeling so comfortable with a chain of reasoning that we have not questioned the results sufficiently. We intend to create a resource that can be applied to train the reflexes and intuition of engineers to continuously question both analyses and experiments; also emphasizing that simple experiments can provide insights and guide approaches to solving quite complex problems. The following section provides examples of the problem-solving reflexes to everyday phenomena that we are trying to engender.

Motivation

The student was taking fluid mechanics that semester, but it was spring break, and she was driving home. It was a pretty warm day, and after seeing a semi-truck in front of her "peel" a tire, she began to estimate, as she drove along, the effects of temperature on the pressure inside a tire. Then, curious as to how big a role speed had played, she began to estimate the magnitude of the effect centripetal acceleration would have on the tread pressure. Later that day, she drove under some power lines and noticed interference with an AM station on the car radio. She realized that AM frequency power could not come from a 10 w frequency power line if the system was linear. But what was the salient nonlinearity? The power in higher harmonics should be lower. To test this, she turned the car around and switched the radio to FM...

Looking out into a classroom of young faces today, it is easy to wonder how many of them use their classroom learning to question the phenomena they see from day to day. What percentage of engineering students regularly attempt hands-on explorations of everyday happenings they see in their home or their car? The percentage is way too low, and this is a shame because explaining phenomena in a hands-on and analytical way is very, very educational, as well as just plain fun.

We believe that one reason students today don't naturally explore everyday problems is that the formal laboratory is now the overwhelming choice for exercising or illustrating theoretical material being delivered concurrently in the classroom. The problem here is that students are trained and encouraged to apply learned theory only to elaborate problems in limited, closed, and usually supervised settings.

- An example of how simple experiments figure prominently in the thinking of first-rate scientists is the "kitchen sink" experiment performed by Richard Feyman in the investigation of the Challenger disaster. By simple freezing an "o" ring, he vividly showed how brittle it became, identifying one potential cause of material failure in a way that could easily be comprehended.

The following anecdote from a fluid mechanics class illustrates the pedagogical usefulness of experimental homework assignments to complement traditional pencil-and-paper problems. Students in the particular class were asked to perform a simple experiment at home creating a hydraulic jump in the kitchen sink. They were asked to measure the radius at which the jump occurred and compare it to the theoretical solution, then comment on the results. A typical response of many in the class to explain the inevitable discrepancy was, "There must be something wrong with my experiment!"

Goals and Objectives

Our vision is to pioneer experimental course complements that can be used to exercise or illustrate theoretical material. In contrast to the formal laboratory, a hands--on-homework will be a simple but elegant hands-on experiment that can be done in routine places with simple equipment. The key goal of hands-on-homework is to encourage and train students to apply and test rigorous theory in unsupervised, ordinary situations involving phenomena seen in the course of everyday life. The idea is to nurture a student's natural day-to-day curiosity and mesh it with rigorous theory s/he is learning in class.

The objective is to create a portfolio of experiments that could and would be assigned exactly like homework problems. The experiments are designed to be performed by the student in the home, using readily available materials. All equipment and instruments needed can be found around a typical house, purchased at a five-and-dime for a buck to two or, worst case, checked out from the instructor for a short period of time. Every experiment would directly test, challenge, or verify a theoretical concept, and the student would be required to generate a comparison between theory and experiment.

It is widely understood that exploring the puzzles and mysteries of day-to-day phenomena is fun and educational. Witness the large numbers of children's books[1,2,3] that aim to get children interested in, and learning about, science in this fashion. There are, of course, many distinctions between a hands-on-homework and a child's experiment. A key distinction is the required use of theory to predict/explain/compare and the idea that hands-on-homeworks also seek to foster a healthy habit of questioning and skepticism in addition to reinforcing a student's natural curiosity and wonder.

Project Description

Prototype Examples

Several prototype HOH problems have been tested at both the undergraduate and graduate level, in a course, Environmental Aerodynamics, verifying the great need for student "reality checks." In many cases, students ignore the lessons from their experiments or consider the experiments flawed. Two sample HOH exercises follow:

Hands-on-Homework No.1

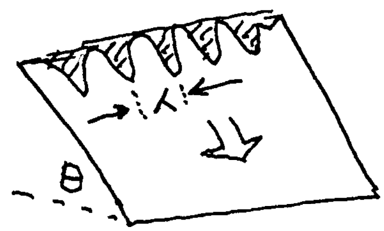
Title: Flow of a Viscous Fluid Down a Slope

Supplies:

- salad oil or liquid soap (approximately several teaspoons)
- metal cookie sheet or movable flat metal surface

Topics/Concepts/Principles Addressed:

While watching someone work in the kitchen, you note that salad oil spilled on a cookie sheet flowed downward under the force of gravity, producing interesting instabilities at the leading edge as sketched below:



Procedure/Homework Exercise:

1. Repeat this "kitchen sink" experiment and comment on the results.
2. Although the liquid is quite viscous, you assume the important parameters controlling the instability are the following:

l	the wavelength
s	the surface tension
g	the gravitational acceleration
A	the initial area of the spill
r	the density
q	the dimensionless slope angle (treat as a modification of g)

a. Apply dimensional reasoning and obtain an expression relating these quantities.

b. How will the wavelength change as the slope angle is reduced?

3. Make a rough estimate for the constant relating the wavelength to the other parameters using a value for s of 60 dynes/cm and a density of 1 gram/cc.

Hands-on-Homework No. 2

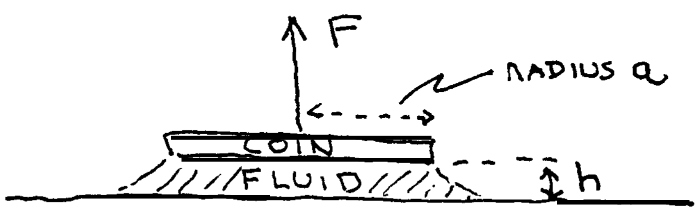
Title: Pulling a Disc Away from a Surface
When the Two are Separated by a Thin Film of Viscous Liquid

Supplies:

- coin
- viscous fluid such as honey (approximately one teaspoon)
- flat, washable surface (such as a table or counter)

Topics/Concepts/Principles Addressed:

It can be very difficult to pull a disc away from a flat surface when a film of a viscous fluid separates the two. The configuration is sketched below:



Procedure/Homework Exercise:

1. You need to determine the important combinations of variables controlling the force required and assume the following must be included.

F	force required
m	molecular viscosity
h	height of the fluid
a	radius of the disc
dh/dt	the rate of change of fluid height

Note: In your answer, assume that the force is proportional to a^4.

2. Place a coin on a table coated with a viscous fluid. Remove it in various ways and contrast your observations with the results of your analysis.

Method, Timetable and Deliverables

The method, timetable, and the deliverables are itemized below:

1. Preliminary Work: Develop several prototype hands-on-homeworks in the area of fluid mechanics and pilot them in the Environmental Aerodynamics course offered by the Department of Aerospace Engineering Sciences.

2. First Six Months: Develop an "outreach" program to faculty in all disciplines who are teaching theory courses. The intent is to educate faculty about the hands-on-homework concept and work with them to identify candidate experiments. Perform this outreach through an already established network of curriculum development teams of College faculty formed to assist in the curricular components of the Integrated Teaching and Learning Laboratory (ITLL). The network consists of more than half of the College's faculty, covers eight interdisciplinary focus areas, and includes all six departments. An effort is currently underway to solicit HOH concepts from the faculty at large.

3. Six Months -12 Months: Develop a significant number of hands-on-homework problems in a broad range of disciplines. Each will have the following characteristics:

   a. it is amenable to experimental verification using simple materials or devices (ideally available in the home);

   b. the physical process is such that qualitative results concerning trends can be obtained in an unambiguous way; and

   c. there is a close, natural connection between theoretical results and the hands-on-homework assignment. The student is guided, but not pushed, to a meaningful theoretical analysis and asked to compare/verify the final experimental result against this.

4. 12 months -18 months: Develop kits and accompanying write-ups for hands-on-homework that can be assigned in undergraduate courses taught by the authors. We plan to first test hands-on-homeworks in undergraduate classes in our respective areas of expertise.

   After one semester of debugging, distribute refined kits to other instructors of undergraduate courses. The authors will assist these instructors in evaluation and gathering of performance data.

5. 18 months -24 months: Produce a "user's guide" that details and summarizes the hands-on-homework produced as well as the data gathered in evaluating their use and effectiveness. This guide book will be an easily exportable resource. Since experiments in the book will be elegant but simple and do not require expensive equipment or resources, they should be readily adaptable by instructors at other universities.

   The user's guide will be made widely available (possibly in the form of a book) and progressive results including evaluation data will be presented semi-annually at the ITL External Review Workshop[4]. We can thus present our results to, and get feedback from, major institutions and members of many of the NSF engineering education coalitions including: Foundation, ECSEL, Synthesis, and Gateway.

6. Program End: Establish an electronic mail "clearinghouse" to gather and disseminate hands-on-homework ideas, data, uses, etc.

Design Approach

The inspiration for HOH problems has come from a variety of sources. In some cases, an interesting effect observed in the home (e.g., the appearance of candle smoke after a flame is blown out) served as the motivation for a problem. In other cases, the theoretical or numerical problem came first and naturally suggested the simple experiment. We are continually surrounded by interesting and often puzzling phenomena and it is challenging to become sensitive to these. "Keeping it simple" and yet providing an important experience was also a challenge.

Important resources for suggesting and development HOH assignments exist. These range at one extreme from the children's books[1,2,3] already mentioned as well as others[5,6]. Although these lack rigorous background information, they can pose interesting theoretical questions. Another set of resources provide a higher level of presentation of physical phenomena, providing physical insights and/or references for further reading[7,8,9,10]. An additional area includes texts that document full-scale laboratory experiments [11,12,13]. Many times quite simple, although more qualitative experiments can be distilled from these more formal laboratory experiments (which typically require an array of special purpose instruments and hardware). However, in many cases we have (in addition to the HOH) also performed a more detailed experiment to provide a quantitative reference point. Where appropriate, we also plan to highlight dynamic analogs[14] that show, for example, how a fluids experiment can illustrate the operation of an electronic circuit. We have tried to document the source inspiration for each HOH developed as well as to provide reference materials.

Development Philosophy

We have developed HOHS in a number of ways. Most often a theory problem existed and a simple companion experiment needed to be created. We were fortunate to have several creative graduate students working using our NSF support on these assignments. Typically, the simple experiment was designed and tested first. Following this, we often developed a classroom demonstration as well as a more sophisticated laboratory experiment so that we could also provide students with data showing a quantitative comparison. A detailed write-up documenting the required hardware completed each HOH developed.

In addition, undergraduate students needing design credits are also working on HOHS. A typical, challenging HOH is assigned one credit when successfully completed.

Evaluation and Impact

Ultimately, hands-on-homework assignments will be liberally sprinkled throughout the engineering curriculum at UCB. They will be an integral part of an overall curriculum revision taking place to accommodate and utilize the Integrated Teaching and Learning Laboratory (ITLL) at the University of Colorado at Boulder. The ITL is a $15M, 34,400 sq. ft. building that will have a 16-hour open access. Construction began in October 1995, and there will be an area of the ITLL especially for hands-on-homework. This area will accommodate students who wish to conduct hands-on-homework with groups of fellow students, those who do not wish to wait until they are at home to perform the experiments, or those who simply find the ITL the easiest and best place to do a hands-on-homework assignment.

We envision that hands-on-homework assignments will get students to apply what they learn in the classroom to what they see everyday, with enormous impact. This fundamental benefit is not an easy one to directly assess, and we will have to rely on much anecdotal information. However, we propose to also obtain a more quantitative assessment by using the following procedure:

1. randomly divide each class into two equal sized groups;
2. give, on a regular basis, hands-on-homework to only one group; and

3 evaluate the effectiveness of hands-on-homework by holding consensus group evaluations at two points in the semester and by statistically comparing overall performance of the two groups.

Concluding Remarks

We remain eager to discuss HOH concepts with teachers from other institutions as well as to share problems already developed or in progress. Appendix A contains a listing of HOHs together with their status.

Appendix A

HOH Completed

1. Flow of a viscous fluid down a slope.
2. Spreading of a viscous drop.
3. Pulling a disk away from a wet surface.
4. How to keep honey on a spoon.
5. Drop of liquid striking a liquid surface and the vortices created.
6. Standing Hydraulic jump.
7. Oscillation of a pool of dense air in a valley
8. Buckling flows.
9. Film of liquid on a vertical plate.
10. Oscillating fluid in a tube.
11. Faucet standing waves.
12. Phase plane analysis of a chair.
13. Frequency response, resonance, and a simple pendulum.
14. Why put backspin on a basketball?
15. The sweet spot of a bat.

HOH in Progress

1. The major axis rule - or - Why does an egg spin like it does?
2. A faucet stream becoming disturbed as it falls.
3. Fishing line and a water surface.
4. Vibrations of solids.
5. Thermal plumes.
6. Nappe oscillations.
7. Capillary waves and long period waves.
8. Jet of air impacting water with and without surfactant.

HOH in Planning

1. Helmholtz resonators.
2. Surface tension and water column heights in tubes.
3. Corrugated tube sounds.
4. Tapping containers containing liquids and other adventures.
5. Coffee cup convection cells.
6. Tube resonances.
7. Salt fluid oscillators.

8. Jumping honey.
9. Signal aliasing or hum along with your TV.
10. Flapping flags.
11- Effect of a comb on a stream of water.
12. Model an oil spill in your kitchen sink.
13. -Viscous fingering.
14. Stability of a surface tension interface.
15. Fun with Hele-Shaw cells.
16. Density currents in your home and work place.
17. A tar barrel spill.
18. Convection.
19. Liquid drop dances on hot plates.
20. How to design a fly swatter.
21. Sounds from red balloons.
22. Sounds from your water faucet.
23. Cooking times of turkeys and other things.
24. Icicle mysteries.

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Biographical Information

ALFRED J. BEDARD, JR.
Dr. Bedard is an expert in the design of instrumentation and techniques for the detection and study of acoustic gravity waves in the atmosphere. He has been a supervisory physicist with the Environmental Technology Laboratory of NOAA since 1966, and he has been an adjunct associate professor of Aerospace Engineering Sciences in the College of Engineering and Applied Science at the University of Colorado since 1988.

DAVID G. MEYER
Dr. Meyer's research activities center around the modeling and control of advanced dynamic systems. He was on the faculty of the University of Virginia for four years where he was the recipient of the Young Faculty Teaching Award. He joined the University of Colorado at Boulder in 1992 and is an Associate Professor of Electrical and Computer Engineering in the College of Engineering and Applied Science.