You Don't Need a Weatherman to Know Which Way the Wind Blows: The Art & Science of Flow Visualization

Jenn Stroud Rossmann and Karina Aguilera Skvirsky
Lafayette College, rossmanj@lafayette.edu, skvirskk@lafayette.edu

Abstract - **The flow of fluids explains how airplanes fly, why a curveball curves, why atherosclerotic plaque clogs arteries, why Jupiter's red spot is changing size, and how hurricanes form. Yet it is difficult to *see* fluids flowing: you can't see the wind, or ocean currents, without the techniques of *flow visualization*. Flow visualization reveals an invisible world of fluid dynamics, blending scientific investigation and artistic exploration. The resulting images have inspired, and in some cases themselves become appreciated as, art. At Lafayette College, a sophomore-level seminar in *The Art and Science of Flow Visualization* exposes students to these techniques and the science of fluid mechanics, and to the photographic methods needed to create effective images that are successful both scientifically and artistically. Unlike other courses in flow visualization, this course assumes no a priori familiarity with fluid flow or with photography. The fundamentals of both are taught and practiced in a studio setting. Students are engaged in an interdisciplinary discourse about fluids and physics, photography, scientific ethics, and historical societal responses to science and art. The development, implementation, and assessment of this team-taught course will be discussed.**

Index Terms – Interdisciplinary, Fluid mechanics, Photography, Seminar

INTRODUCTION

Flow visualization is a family of techniques used to reveal the details of fluid flow. Leonardo da Vinci is widely recognized to be one of the first practitioners of this scientific art. He spent many years in his makeshift laboratory and in the field observing the movements of water and air. During his research, he maintained detailed notes and drawings to record his observations. A sketch from Leonardo's notebooks of a free water jet issuing from a square hole into a pool represents perhaps the world's first use of visualization as a scientific tool to study turbulent flow.

As the quintessential "Renaissance man," Leonardo would likely "not have recognized our contemporary opposition of art and science"[1]. The disciplinary boundaries that have since grown up separate two fields both concerned with inquiry, discovery, and revelation of truth. While there are distinct differences in the methods and values of these two fields, there is much to be gained by engaging in an interdisciplinary study of both fields – with benefits both for specialists and for undergraduate students who may not yet accept the immutability of disciplinary boundaries.

Introducing non-engineering students to engineering methods, values, accomplishments and challenges enhances a liberal arts education and better prepares non-engineering students for careers in law, medicine, policy, or other fields. Courses developed for non-engineering students at Princeton University [2], Hope College [3], and other institutions have proven to be effective in achieving outcomes such as technological literacy and appreciation of engineering methodologies.

We found the example of a team-taught class at the University of Colorado, Boulder, particularly inspiring [4]. Their flow visualization course serves as a technical elective for advanced mechanical engineering and art students, with a substantial graduate student enrollment. Students are partnered with classmates so that the engineers share their expertise in fluid mechanics and laboratory technique, and the art students help their teammates with photographic equipment and techniques. At Lafayette College, our objective was to develop a course for lower division students that would *introduce* them to the vocabulary, methods, and values of both engineering and art. This differs substantially from the Colorado model in that our students, as sophomores, are participating in our interdisciplinary course *before* their own disciplinary expertise (or bias) is established. Our syllabus, assignments, and objectives are therefore distinct.

This course is offered with Lafayette's VAST [Values and Science/Technology] designation, a component of the common course of study [5]. Each sophomore student is required to complete one VAST course. Courses with the VAST designation are writing-intensive seminars, involving interdisciplinary integration and multiple disciplinary approaches to course material, and address ethical or moral issues related to modern technology.

IMPLEMENTATION

Anyone who has paid attention to the patterns formed while stirring milk into coffee, or stared at the curl of a rising tendril of smoke, has participated in flow visualization. Images of flow fields can be both beautiful and instructive, as is demonstrated by the success of such collections as Milton Van Dyke's *Album of Fluid Motion* [6] and of online sources like the American Physical Society Division of Fluid Dynamics' Gallery of Fluid Motion [7], whose potential for general impact was demonstrated by a recent New York *Times* article [8]. Resources intended to enhance students' understanding of fluid mechanics in technical courses have proven to be distractingly hypnotic [9].

The *science* of flow visualization lies in the techniques that can reveal invisible swirls and cascades and wavefronts, and in the physics that is illustrated. The *art* is in the thoughtful choice of techniques, and in the composition and presentation of the images. Images can be used to elucidate, prove, or even distort scientific concepts. Course content for *The Art and Science of Flow Visualization* thus includes historical context and modern methods from two fields, as well as the ethics of scientific imagery.

FIGURE 1
EXAMPLE OF STUDENT WORK: SEQUENCE OF PHOTOGRAPHS BY KELLY RODRIGUEZ ILLUSTRATING NEGATIVE BUOYANCY OF COLD MILK IN HOT TEA.

The course syllabus includes introductions to fluid mechanics and photography, and many discussions of the intersection of art and science. Developing and teaching this course in an interdisciplinary team allows us to draw from the pooled expertise of two fields. For example, the landmark flow visualization example of the Worthington droplet is discussed, and Worthington's influence traced through the fine art and literature of his contemporaries, to Harold Edgerton's Strobe Alley and the modern artists Ned Kahn, Martin Waugh, and the partnership Magsamen-Hillerbrand, whose video work *Coffee and Milk* is an accidental flow visualization textbook.

The course content addresses the physics of fluid mechanics, the roles certain fluid flows have played in cultural products such as art and literature, and the creation and critique of the students' own work visualizing such flows. The students' images become illustrations that help them understand both fluid mechanics and photographic technique. The course objectives are stated on the syllabus as presented in Figure 2.

Course Objectives

In this course we will use lecture, discussion, lab and studio time to help students develop:

- Ability to interpret flow visualization images and understand physics of fluid flow
- Technical and photographic expertise to create meaningful flow visualization images
- Appreciation of aesthetics of [scientific] imagery
- Ability to consider the ethical responsibility of presenting an image as "truth"
- Understanding of the historical development of photography from science to art
- Ability to explain technical concepts in clear, thoughtful language *and pictures*.

FIGURE 2
COURSE OBJECTIVES AS STATED ON SYLLABUS

Some flows are visible without the use of sophisticated laboratory techniques: one example is found in the clouds. Clouds are formed through the condensation of water vapor, which is typically caused by cooling. Cooling, in turn, is often caused by the uplifting of air. That is to say, warm air rises, until it slows down and cools. At that point, water vapor in the air may condense and become a cloud, and the cool drier air can fall back to the earth's surface to be heated and lifted, and so on.

One of the first to classify clouds was England's Luke Howard in 1803. Howard's book was the scientific coffee table book of its day, read widely and discussed in salons. Shelley wrote a poem called "The Cloud," using Howard's scientific jargon alongside very sentimental, romantic language. Goethe is said to have pressed copies of the book on people he met at cocktail parties, and urged his visual artist friends to look up at the sky for inspiration. He himself wrote a series of poems called "In Honour of Howard," praising what he called Howard's "gentle empiricism," and describing the movement: "As clouds ascend, are folded, scatter, fall," Goethe wrote – describing, beautifully, the cycle of the convection-and-condensation cell that creates clouds.

The fine American photographer Alfred Stieglitz created a series of his photographs of clouds, which he called "Equivalents," for example the image in Figure 3. He considered these images *equivalent* to music, stripped of context, their only "messages" or "meanings" in symbolic terms.

One can find a modern parallel to Stieglitz in the decontextualized scientific images of Felice Frankel [10], which often appear on the cover of *Science* and *Scientific American* to show the beauty, if not clearly the meaning, of the studies detailed inside.

FIGURE 3
EQUIVALENT 1930, BY ALFRED STIEGLITZ

The syllabus for this course, as the preceding paragraphs indicate, does not acknowledge the barrier between art and science, and revels in eroding whatever barriers students may have previously perceived. Course discussions address questions such as "what makes an image art?", "what makes an image scientifically relevant?", and "how can photography enhance and/or distort understanding of scientific concepts?" In writing assignments, students respond to reading from both disciplines, make connections, and continue to grapple with the larger questions. In photographic assignments, students made and analyzed their images of fluid flows both in naturally occurring environments and in constructed settings designed by them to illuminate fluid phenomena they had learned about in class, such as vorticity, buoyancy, and the distinction between laminar and turbulent flow.

Critical to the success of this course is a studio or laboratory approach, allowing students to gain hands-on experience with the equipment and techniques used in flow visualization during course discussions. Students create their own physical models and images for course assignments outside of class, and bring those experiences into the classroom for wider discussion with faculty and classmates.

Also important is the existence of a teaching team comprised of two members from both engineering and art (or art history). These fields involve different approaches, vocabularies, and values, and it is a primary objective of this course to expose students to the methods of different disciplines and to encourage interdisciplinary discussions and collaborations.

An exhibition of student work at the end of the semester enables the wider community to see what the students have learned, and to engage in the discussion. Students complete and turn in a final portfolio of 6-10 images from their work over the semester, with written reflection on the content, creation, significance, intention, and effectiveness of each image, as well as a longer discussion of the portfolio as a whole.

ASSESSMENT

The students in *VAST 217: The Art and Science of Flow Visualization* represented all four academic divisions of the College. They learned to consider how much context to include in their work; how to construct a narrative; when to choose abstraction over exposition. They've performed experiments in wind tunnels and on the quad. They have discovered fascinating fluid flow in a variety of places, from a candle to a coffee cup, from a kitchen sink to the sky.

Students from all majors have struggled with the jargon and concepts of both art analysis (for example, readings from Graham Clarke's *the Photograph)* and fluid dynamics. We had not initially anticipated the magnitude of this difficulty, so we adjusted the syllabus and facilitated small-group discussions and exercises to help students unpack and understand this material. We also underestimated the amount of help students would need familiarizing themselves with their cameras and with Photoshop.

Student work and writing reveals students' successful synthesis of the scientific and artistic course content, and their increasing comfort with the casual (and correct!) use of engineering terminology and methods. Students reported that they became aware and appreciative of fluid dynamics in their everyday life, as representative student feedback indicates:

> *As the semester progressed I began seeing fluid flow everywhere, pointing out examples to all of my friends, who also caught onto the trend.*

> *After a few weeks in this course I would run outside to watch the rain flow along the edges of the street and sidewalk.*

> *I now accept that [art and science] are so deeply connected that it may not be possible to discern where one ends and the other begins.*

> *Now I understand that science is more than calculation and experimentation. It can be beautiful!*

Entry and exit surveys are used to quantify student engagement and achievement of learning outcomes. One notable result is the increase in students' "awareness of and familiarity with" both photography and fluid dynamics, illustrated by Figure 4.

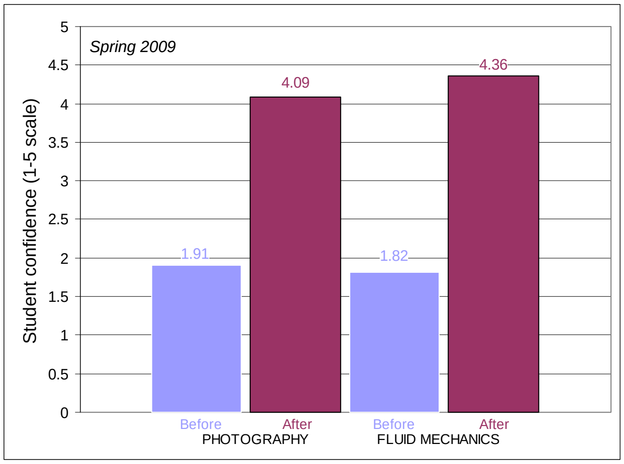

FIGURE 4
STUDENT SURVEY DATA REFLECTING STUDENT CONFIDENCE IN THEIR AWARENESS OF AND FAMILIARITY WITH THE METHODS OF PHOTOGRAPHY AND OF THE PHYSICS OF FLUID FLOW.

CONCLUSIONS

This interdisciplinary course at Lafayette College has introduced sophomore students from a variety of majors to techniques of science and art, and to the interactions of these disciplines. While the benefits of broader contextualization and liberal arts instruction for engineering students are often extolled, this course offers non-engineering students an entrée into the engineer's approach to problem-solving and perspective on the world. Lessons learned from the first two offerings of this course have been used to refine the approach.

ACKNOWLEDGMENT

The authors are grateful for the support of the Lafayette College Provost's Fund for Faculty Innovation, and for the resources provided by NSF grant CTS 0552104. They also thank Bob Dylan for providing the title of this paper.

REFERENCES

[1] Gharib, M., Kremers, D., Koochesfahani, M.M., and Kemp, M., "Leonardo's vision of flow visualization," Experiments in Fluids 33 (2002): 219–223.

[2] Billington, D.P., "Engineering In The Modern World: A Freshman Course In Engineering," *Frontiers in Education Conference,* 1993, Pages 45 – 52.

[3] Krupczak J.J., "Science and Technology of Everyday Life: A course in technology for liberal arts students," *Proceedings of the1996 American Society for Engineering Education Annual Conference* (1996) American Society for Engineering Education.

[4] Hertzberg, J. and Sweetman, A., "A Course in Flow Visualization: the Art and Physics of Fluid Flow," *Proceedings of the 2004 American Society for Engineering Education Annual Conference* (2004) American Society for Engineering Education.

[5] Sanford Bernhardt, K.L and Roth, M.J.S., 2002, "Active ethics: philosophy, cases, and writing," *Proc. 32nd ASEE/IEEE Frontiers in Education Conference,* Boston, MA: S4F1-6.

[6] Van Dyke, M., *An Album of Fluid Motion,* Parabolic Press, 1982.

[7] Gallery of Fluid Motion, American Physical Society, http://www.aps.org/units/dfd/

[8] Schecter, B., "From Flowing Fluids, Beautiful Images and Unlocked Secrets," New York *Times*, June 24, 2003.

[9] Homsy, G.M., Aref, H., Breuer, K.S., Hochgreb, S., Koseff, J.R., Munson, B.R., Powell, K.G., Robertson, C.R., and Thoroddsen, S.T., *Multimedia Fluid Mechanics DVD-ROM,* Cambridge University Press, 2008.

[10] Frankel, F., *Envisioning Science*, MIT Press, 2002.