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Expanding Perception: How Students "See" Fluids

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My research has focused on human memory since the early 1990s. This has included cognitive/behavioral studies, neuropsychological studies in brain-injured patients, positron emission tomography (PET), fMRI, MEG, as well as ERP. I have run my own ERP lab since 1995, and have been continuously funded to conduct ERP studies of recognition memory since 1997 (McDonnell-Pew Foundation: 1997-2001; NIMH/NIH: 2002-2012). Around 2000, I also began conducting ERP and behavioral research related to perceptual expertise. This work has been continuously funded since 2001 (McDonnell Foundation: 2001-2010; NSF: 2006-2016).

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Expanding Perception: How Students "See" Fluids

Since 2003, the University of Colorado Boulder has offered a course called Flow Visualization (Flow Vis). It is cross-listed as a mechanical engineering elective and a fine arts studio course, and brings together mixed teams of engineering and fine arts photography or film students. It focuses on the production of aesthetically pleasing and scientifically useful images of fluid flows. Flow Vis students have responded enthusiastically, with exit survey comments such as "I'll never ignore the sky again" or "I see examples of flow vis all the time now."

In prior work, participation in this course was linked with a positive shift in affect with respect to the subject of fluids, which we measured through the Fluids Perception Survey (FluPerS)[1]. This was in contrast to the survey results from Fluid Mechanics, a traditional engineering core course, with a highly analytic, mathematical approach. Exit surveys of students in Fluid Mechanic reveal a negative shift in affect toward fluids, which is typical of other technical courses and their content areas.

More specifically, the responses from Flow Vis students can be termed an "expansion of perception" – when learners see everyday objects, events, or issues through the lens of the content[2]. Expansion of perception is often associated with deeper conceptual understanding and the ability to transfer learning to new settings. To investigate this expansion of perception, our research has taken a two-prong approach. For the first prong, we continue to examine the classroom environment using ethnographic and qualitative research methods.

The second prong, presented here, looks at how individuals learn to perceive fluid flows and understand them. Working with colleagues in Psychology, we developed a visual expertise experiment. The initial proof-of-concept experiment (n=6) demonstrated that subjects can improve their perception of fluid flows, sorting images into turbulent and laminar categories, after one session of training with feedback and without any explicit instruction about flow visualization. These results encouraged us to increase the complexity of the perception training, and we have begun a pilot of the experiment with novices (n=24 so far) and experts (in this case, students who have completed Fluid Mechanics) (n=5). The eventual goal of this work is to create a reliable, valid measure that can gauge whether students of fluids are gaining visual expertise over the course of a semester of study.

Introduction:

One challenge in learning is making the leap from using certain ideas previously situated in the classroom to applying them outside the classroom. Education researchers have called this the transfer problem[3] or referred to it as the need to "activate resources"[4]. Yet, we often talk about learning in terms of "seeing," or new awareness of how things work. Building on this intuition, one group of education researchers has characterized an expansion of perception as when learners see everyday objects, events, or issues through the lens of the newly-learned content[5]. Clinically, perception is how our senses tell us about the world and our state within it, using our nervous system. Just as our heart rate does not catch our attention until it changes significantly in some way, many details of our everyday experience do not stand out in our perception until we learn that they are important to notice. This sort of perception can be learned, and it is context-specific. For example, experienced radiologists who quickly and accurately find potential cancer cells in medical images were no better than lay people at finding target items in a non-medical image[6].

Like the radiologists, experts in other fields learn which aspects of a problem they must attend to, and which they can safely ignore when working those problems. Experts more quickly perceive the relevant information in their environment, and instead of mentally categorizing something at a basic level, and then a subordinate level, can often go directly to subordinate level identification[7]. For example, a novice bird watcher, in attempting to identify a bird, might see a bird and think, "song bird → finch→finch with red and brown feathers" and then have to dig out a bird book to further identify the specific species, house finch. The expert sees the bird, immediately identifies it at the subordinate level as "house finch" and can move on to more important research questions about nesting habits or migration patterns. The novice must move through basic categories first to find the correct subordinate-level category, if they are even able to identify at that level at all; the expert can often go directly to that level.

Another example of categorization is the grouping of physics problems. Chi, Fletovich, and Glaser found that while physics experts grouped problems according to the "major physics principle governing the solution," novices relied on surface features (e.g. the diagrams all include pulleys) or by the keywords present in the wording of the problem[8]. Although more abstract than the bird-watcher example, this example also shows how experts' perceptions are developed in particular ways. Students, as novices, often do not perceive which details in the problems are most important, and are likely to place the highest importance on those aspects that are graded. If we do not align the grading with the most important aspects of the concepts, students can pass through the course without learning the concepts. Developing that conceptual understanding does not come "for free," but rather is part of a "hidden curriculum" that instructors must make explicit and must find ways to assess[9]. It seems pertinent then, to find what experts notice about their work, and design courses to better focus on those aspects, including the visual ones. Only then will students' learning actually align with the goals of the course, and far more students will find their perception shifting from that of a novice toward that of an expert.

Background:

This study is motivated by past work with a technical elective course called Flow Visualization (Flow Vis). It focuses on the production of aesthetically pleasing and scientifically useful images of fluid flows, and requires short papers describing the forces at work in the images. The course emphasizes the aesthetic qualities of the images, and draws frequent comments from students that indicate an expansion of perception, which co-occurred with a positive shift in affect. That is, students in Flow Vis reported both that they notice fluid physics in the world more frequently and that the subject of fluids is important to them as engineers and to society in general[1]. Intuitively, the links between an emphasis on aesthetics, the positive shift in affect, and the self-reported expansions of perception seem clear, however, we wished to establish a more concrete, measurable link between them.

To create that link, we model our investigation on those of other types of visual expertise, such as face recognition[10] and experts' encoding and memory of cars and birds[11]. The work described here aims to define and establish a measure of visual expertise in fluid physics. Although it may be a long process to connect these experiments to the classroom, the ultimate goal would be to create measures that help us determine if a course is successful in helping students gain relevant perceptual expertise in that field.

Methods:

Participants

Subjects were ages 18-30, with normal or corrected-to-normal vision. They gave informed consent to participate in the study, as per the protocol approved by the Institutional Review Board. Subjects were recruited via fliers and email, and were paid $10 per hour for their participation. Initial versions of the experiment recruited self-reported novices in fluid dynamics; a later version specifically sought relative "fluids experts" by recruiting from students who recently completed fluids courses.

Materials

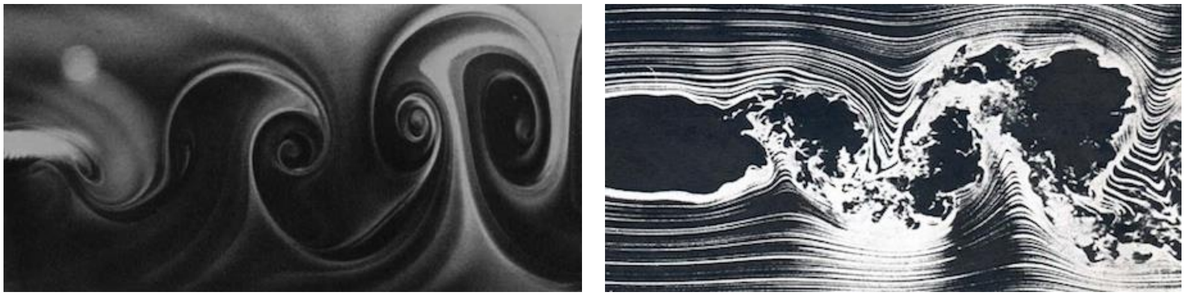
These experiments were programmed in MATLAB (version R2013b, The MathWorks, Inc., Natick, MA) using a locally-developed experimental framework[a] and presented with Psychtoolbox, an open source set of functions for vision and neuroscience research.[12] This allows the experiment to be presented on a computer, limiting what keys or other controls the subject can use. Subjects viewed the experiment on 17-inch flat-panel displays with a resolution of 1024×768 (60 Hz frame rate) placed one meter in front of the participants, and used a standard QWERTY keyboard.

Image Selection and Processing

For these experiments, the categories of images were turbulent and laminar fluid flows. To verify that images were correctly classified as either turbulent or laminar, two professors who regularly teach fluids classified them independently. If an image was in doubt or labeled "transitional" by either professor, it was not used.

One specific type of image used was of Von Kármán vortex streets, a type of fluid flow that can be either turbulent or laminar. Twenty images of each category were included as stimuli for the experiment for a total of forty vortex street images. Another group of images (called "General") contained a wide variety of flows (none of which were vortex streets), were also categorized as either laminar or turbulent, and likewise, 20 images from each category were included. All images were processed to be gray-scale, and within a specific size range. All vortex street images were oriented with the flow going from left to right. All portions of the display not covered in images or text during the experiment were presented as gray pixels. Figure 1 shows exemplars of the images used.

[a] https://github.com/warmlogic/expertTrain



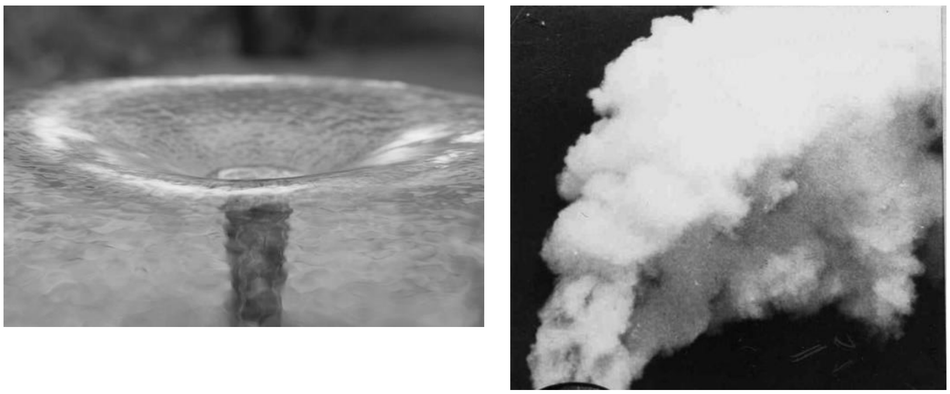


Figure 1: Processed image examples. Top left – laminar vortex street[13], Top right – turbulent vortex street[14], Bottom left – laminar general flow[15], Bottom right – turbulent general flow[16]

Experiment Design

Subjects received instructions that covered what to expect from the format of the experiment, but nothing regarding the nature of the images they would see or what the categories would be. The experiment was conducted in a single session. Within the text of the experiment, the categories were called 1 and 2 to avoid any misinterpretation due to subjects' prior familiarity with the words "turbulent" and "laminar."

Three different types of tasks were used in these experiments:

- Matching tasks: subject shown two images, one after the other, and must indicate whether the two images are the same or different in the relevant category. For our experiments, matching tasks were always used as the testing tasks, and subjects received no feedback.
- Naming tasks: subject shown a single image, and must indicate if the image fits category one or two. For our experiments, this was used as the training phase, and subjects received feedback for their actions. When correct, they saw a green-colored "Correct!" and heard a high-pitched beep, and when incorrect, they saw a red-colored "Incorrect" and heard a low-pitched beep.
- Viewing tasks: subject shown a single image with label of correct category the image fits, and is instructed to hit the key for the correct category in order to continue. This was used an alternate training task for our proof-of-concept experiment only.

At the start of the session, subjects completed brief practice tasks in matching and naming using images unrelated to the experiment task, and sorted them into “solid” and “liquid” categories in order to gain an understanding of the controls for the experiment.

During the experiment, half of the images from each category were selected randomly for the training task, while all images were used for the testing tasks. This was to see if training generalized to the untrained images. At the end of the experiment, subjects completed a demographic survey and were asked to write responses for two concept questions:

1. Thinking about your experience in the experiment, how would you describe the two categories of images?
2. How did you decide which images to place in which category?

Proof of Concept:

There was some concern whether subjects could be quickly trained to perform the tasks of distinguishing images along such abstract lines, so an initial “proof of concept” experiment was run, n=6. The experiment used novice subjects. All images in this experiment were Von Kármán vortex streets. Images were shown for 2.0 seconds each. The format of this investigation was as follows:

	Pre-test	Training	Post-test
Group A	Match	Name with Feedback	Match
Group B	Match	View	Match

Table 1: Proof-of-Concept Groups and Tasks

Pre- and Post-tests contained all the images; training was performed with only half of the images. Both groups demonstrated accuracy was better in the post-test than pre-test (50% is chance):

	Pre-test % Mean	Post-Test % Mean	Difference	Learning Gain
Group A (Name)	60%	87%	27%	66%
Group B (View)	58%	83%	25%	60%

Table 2: Proof-of-Concept Results

Learning gains were calculated by finding percentage of improvement shown in the post-test between the pre-test score and a perfect score. That is, learning gain is the actual improvement for each subject out of their possible improvement.

Based on these results, we proceeded with a more complex version of the experiment. The viewing task was eliminated in favor of using the naming task for all training, and new images were introduced.

Experiment and Preliminary Results:

The format of the experiment followed that of Group A in the proof-of-concept above. That is, subjects were given matching tasks for their pre- and post-tests, and a naming task for training. Image display time for each image was reduced from 2.0 seconds to 0.8 seconds, more in line with other visual expertise experiments. In addition, subjects were given a new group of images as an alternate test at the end, a third matching task. Subjects were split into two groups, and the categories for the images were still turbulent and laminar.

	Pre-test (Match 1)	Training with Feedback (Name)	Post-test (Match 2)	New Image Set (Match 3)
Group A	Vortex Streets	Vortex Streets	Vortex Streets	General Flows
Group B	General Flows	General Flows	General Flows	Vortex Streets

Table 3: Experiment Groups and Tasks with Types of Images

Group A was given the pre-test, training, and post-test on Von Kármán vortex streets, and a final test on a general group of images. Group B was given general images for the pre-test, training, and post-test, and a final test on Von Kármán vortex streets.

We currently collecting data on this phase. Initials results are shown in Table 4.

	Pre-Test % Match 1 (mean)	Post-Test % Match 2 (mean)	Alternate type % Match 3 (mean)	Learning gain for type trained (mean)	Learning gain for alternate type (mean)
Group A (Trained on Vortex Streets)	60%	72%	58%	29%	-10%
Group B (Trained on General Images)	54%	61%	61%	11%	11%

Table 4: Experiment Initial Results

We anticipated a dip in scores from reducing the viewing time of images to 0.8 seconds. Even in this limited data (n=24), we can see a tendency for the more generally-trained subjects to be able to apply their training to new types of images, analogous to new contexts. Those subjects trained on vortex streets did make greater improvement in correctly sorting images of that specific format, and yet they were not able to generalize that training to other flow images. On the other hand, subjects trained on more general images made a smaller improvement, but that improvement carried over to the vortex street images as well. See Figure 2.

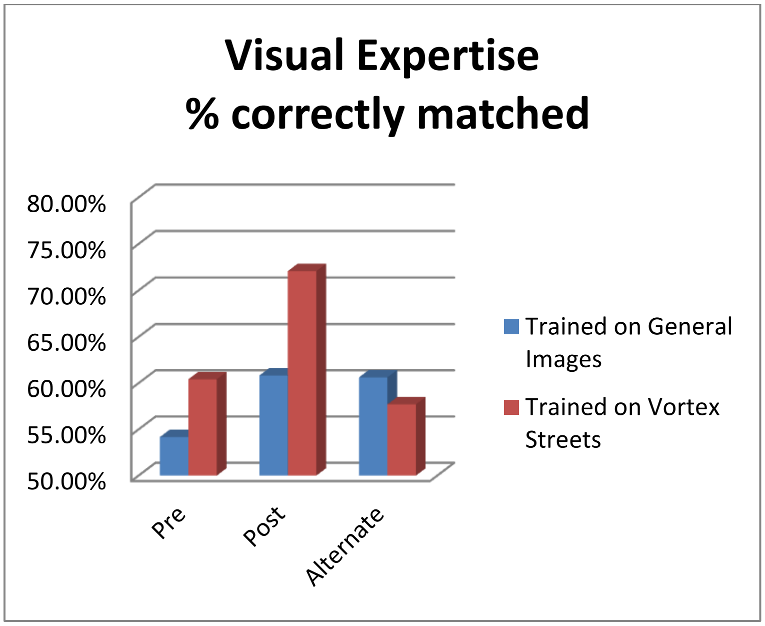


Figure 2: Comparing Training on a Broad Group of Images (General) and a Specific Group of Images (Vortex Streets)

In the next phase of the experiment, subjects with fluids experience are being recruited (students who have recently completed Fluid Mechanics), and experiments with additional dimensions (other than laminar/turbulent) are being considered.

Discussion:

Although we are still collecting data on both the novice and expert versions of the experiment, some possible trends are emerging. If the final data are consistent with these early results, it would suggest that while focusing on specific kinds of examples will produce better results in the short term, exposing students to a broader range of images to help them develop visual expertise would be more beneficial in the longer term.

In the conceptual questions, the subjects revealed that they have some grasp of how they were sorting the images, coming up with nicknames for their categories such as “smoother” and “rougher, more distorted” (Subject 05) or “swirly vs. sporadic” (Subject 04). The novice subjects also expressed confusion or a sense that they never felt sure what the categories were, despite making improvement in the task, post-training. As a counter point, of the five “expert” subjects to date, four have explicitly named the categories of turbulent and/or laminar in the concept questions at the end of the experiment, despite those words never appearing on screen. This bodes well for future iterations of this work, aimed at measuring students’ visual expertise pre- and post-semester, rather than in a single training session.

Possible future steps for this work could include adding more categories of images. For instance, other formats of images other than vortex streets might reveal which formats are easiest to learn.

In addition, we may expand the experiment to include other fluids concept categories, such as jets, shear layers, Rayleigh-Taylor instabilities, or others, in order to get a create a more well-rounded measure of visual expertise in fluids. Future work will continue to explore the connections between the visual expertise and conceptual aptitude in a particular course.

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