Work in Progress: Qualitative Insights from a Visual Expertise Experiment in Fluid Mechanics

Prof. Katherine Goodman, University of Colorado, Denver

Katherine Goodman is assistant professor at the University of Colorado Denver, and the associate director of Inworks, an interdisciplinary innovation lab. She completed her PhD at the ATLAS Institute in Technology, Media, and Society at the University of Colorado Boulder. She also holds a B.S. in mathematics and a masters of professional writing.

Dr. Jean Hertzberg, University of Colorado, Boulder

Dr. Hertzberg is currently Associate Professor of Mechanical Engineering at CU-Boulder. She teaches graduate and undergraduate courses in measurement techniques, thermodynamics, fluid mechanics, heat transfer, design and computer tools. She has pioneered a spectacular course on the art and physics of flow visualization, and is conducting research on the impact of the course with respect to visual perception and educational outcomes. Her disciplinary research centers around pulsatile, vortex dominated flows with applications in both combustion and bio-fluid dynamics. She is also interested in a variety of flow field measurement techniques. Current projects include velocity and vorticity in human cardiac ventricles and large vessels.

Work in Progress: Qualitative Insights from a Visual Expertise Experiment in Fluid Mechanics

Abstract
This work-in-progress explores the qualitative analysis of work modeled after visual expertise experiments in cognitive psychology. In this experiment, participants were asked to sort images of fluid flows as either laminar or turbulent with no prior knowledge of the categories. The two groups of participants were engineering students who had passed a Fluid Mechanics course ("Experienced in Fluids") and students with no prior formal fluid training ("Novice in Fluids"). This experiment included an open-ended inquiry of participant understanding of the task they were performing. (The quantitative outcomes of this experiment are in a forthcoming publication.) We briefly describe the experiment overall, and then delve into how the quantitative results can be explored further through the two open-response questions participants answered at the end of the experiment. Here, we discuss initial coding and exploratory analysis of responses from both participant groups to the following questions: *Thinking about your experience in the experiment, how would you describe the two categories of images?* and *How did you decide which images to place in which category?* We conclude with insights for improving the use of images in Fluid Mechanics courses, and broader implications of how formative assessments might be created for other courses based upon this model.

Background

This experiment grew out of studies of fluid mechanics courses and a fluids elective course, called Flow Visualization [1]–[4]. Students expressed greater fascination and higher engagement in the Flow Visualization course, which required that they create, capture, and describe fluid flows. This process appeared to both enhance their visual expertise in fluids and encourage deeper conceptual understanding of key concepts. In an effort to substantiate this apparent enhancement in visual expertise, we sought collaborators in cognitive psychology, a move being encouraged in engineering education research [5], [6].

Overview of Experimental Design

To explore this connection between conceptual understanding and visual expertise, we collaborated with cognitive psychologists who study visual perception. We emulated a study design from their work in which participants are rapidly shown images and they must perform a matching task with no prior knowledge of the categories. For the purposes of this paper, we will provide an overview of the experiment and summarize the quantitative outcomes. Full detail is provided in our other work [7]. These earlier visual expertise experiments frequently used images of birds [8], [9] or cars [10], [11]. In our case, the images were stills of fluid flows. Instead of categorizing them by bird species or car make and model, participants sorted them by laminar and turbulent. The earlier experiments involved measuring event-related potential (ERP) using EEG nets, with a goal of identifying the brain mechanisms involved and understanding the difference between identifying stimuli at basic and subordinate levels.

In our simpler design, we only looked at participant performance on the task. Participants were not told the categories of laminar and turbulent, but instead had to learn them via trial and error. They performed a matching task (two images shown one after the other, "same or different?") on

20 pairs of images. This matching task was used pre and post training. In the pre-test, the participants were literally guessing; they are not given any ideas as to the categories. Next, the training phase showed participants a total of 20 images. For each image they responded whether the image belonged to Category 1 or 2 and then received immediate feedback about whether they were correct. They then performed the post-test.

Half of all participants performed the pre-test, training, and post-test on a broad selection of flow images, which we called the general group. The other half performed the pre-test, training, and post-test on a specific format of flow, called Von Kármán vortex streets (alternating vortexes in the wake of objects [12]). A final matching test, which we termed an alternate test or alt-test, gave each half of the participants the other set of images in the matching task.

We performed this experiment with 56 "novices" – university students with no prior formal fluids education, and 36 relative "experts" – engineering students who had passed at least one engineering fluid mechanics course. Such courses universally include short discussions of turbulence; the bulk of such courses focus on laminar flows while turbulence is addressed empirically. Half of novices (n=28) were trained on the general group of images; half (n=28) on the vortex street images. Roughly half of experts were trained on the general group of images (n=19), the remainder on vortex streets (n=17).

Prior visual expertise studies suggest that participants learning a specific type of stimulus are usually faster than participants learning to differentiate among broad group of stimuli [13], yet transferring that learning to the broader group is usually challenging. In contrast, participants who learn on the broader group of stimuli usually find adding one more format of stimuli to the task to be easier. In our experiment, this meant that participants learning to sort the vortex streets as laminar or turbulent would presumably have a better post-test score than those who were learning on the general images, but then have a much harder time on the alt-test, when they had to switch to sorting the general category.

We found that, while the novice results were roughly in line with these prior findings, the expert results suggested a different mechanism for learning was occurring. We should note that the quantitative analysis [7] did not reveal many statistically significant results. Two findings did stand out from that work: 1) When we performed a two-way ANOVA on the results, we discovered that a comparison of novices to experts was significant, *regardless of training image group* ($p = 0.0266$, with a 95% confidence interval [-0.6557, -0.0413]). 2) When specifically looking at post-test to alt-test results, novices trained on vortex streets performed significantly worse than the experts trained on vortex streets (ANCOVA analysis, difference in means = -0.51, CI [-0.99, -.0.02] $p=0.04$). Both of these findings suggest that the experts were engaged in learning transfer from their fluid mechanics course to this unfamiliar visual matching task.

Unlike our colleagues in cognitive psychology, we are interested in what participants thought about the task and about their learning of it. So, we added two open-ended questions that all participants answered: *Thinking about your experience in the experiment, how would you describe the two categories of images?* and *How did you decide which images to place in which category?*

Preliminary Analysis of Qualitative Data

We are currently analyzing the qualitative data generated by this experiment. Descriptive statistics reveal no real differences in length (word count) between expert and novice responses. See Table 1.

Group	Mean	Median	Standard Deviation
Experts (36)	73.2	66.5	41.0
Novices (56)	73.5	67.0	36.3

Table 1: Word counts of the two conceptual questions, mean, median and standard deviation

The responses were then coded by emergent keywords. Among experts, 27 of the 36 explicitly identified their task as sorting laminar and turbulent flows. (If participants used the key words "laminar" or "turbulent" or both, they were counted as having identified the task. They did not have to use both words.) Many of these accurate descriptions included other key terms from Fluid Mechanics, such as eddy, Reynolds number, and others. Most mixed technical language with less formal terms. For instance:

"1= turbulent – messy, lumpy, stirred, large scale; 2= laminar – smooth, wispy, clear, small-scale"

Or

"I think the two categories were laminar and turbulent flows. Laminar being smoothly – flowing fluids and turbulent having a lot of eddies."

Among those expert students who did not identify the task correctly (n=9), the most common explanation given was that they believed themselves to be sorting by phase of matter (gases vs. liquids) (n=5). One participant thought the categories were computer generated images vs. photos of natural phenomena ("Visualization (CGI) of a fluid flow vs. physical representation of the flow (clouds, smoke, etc.)"). (Note: all images were photos of flows; no computer simulations were used.)

Among the novices, only two of the 56 identified their task as sorting laminar and turbulent. Even so, their descriptions of the task reveal their grappling, in everyday language, with ideas central to understanding fluids visually. They noticed texture (n=40), with comments such as smooth vs 'chunky' or 'choppy', and found patterns such as 'swirls' (n=30). Many tried to identify the phase of the matter (n=36), often trying to relate a specific texture or pattern to a specific phase state; gas, liquid or solid. These responses are a blend of these different observations. For instance:

"I would categorize the two flows as one being more gaseous and chaotic and in plumes. While the other one was more liquid and streamlines and smooth… I based them off how smooth the flow seemed. If the flow looked more smooth and streamlined I would pick the "liquid" group and if it was more sporadic I would pick the "gaseous" group."

Novices thus demonstrated a naïve visual matching skill, but unsupported by an understanding of the underlying physics.

This study is part of a larger examination of the use of aesthetics in deepening student engagement in engineering topics. Surprisingly, two of the novices mentioned this aspect, although this portion of the study did not mention aesthetics. Subject 1 used categories of 'pretty' and 'not pretty', while Subject 60 said "One category of image was much more aesthetic and organic looking. The other was more chaotic or turbulent".

The phrasing of both novices and experts might be informative for instructors attempting to translate technical terms into informal language for teaching fluids or in public outreach.

Discussion

The first notion that something is wrong with a complex system does not always come from a detailed analysis. Often, it is an experienced engineer noting that something seems "off." A vague comment can motivate a more detailed analysis to either confirm a system is operating safely or that it needs to be corrected. These comments suggest that developing a sense of overall organization of a system is critical in the process of becoming a proficient engineer.

Thus we suggest that the education of engineering students should include more exercises involving looking at complex systems and finding key indicators. Our modest move in this direction is to incorporate more flow visualization into assignments for Fluid Mechanics and related courses. Many instructors already do show images of various fluid flows in their courses, including still photos, videos, computer simulations, and live demonstrations. However, simply viewing these visualizations does not drive learning the way that generating the flows, recording the images, or doing tasks with the images can. In experiments of visual expertise in other topic areas, cognitive scientists have found that exposure to images without doing a related task with them yielded no improvement in visual expertise [13].

Given the expectation of "what gets measured gets improved" that exists in many colleges of engineering, we suggest that a simple sorting test, similar to the experiment described above, could be administered pre/post fashion, to gauge understanding of key concepts in courses such as Fluid Mechanics. This is would be similar to the Force Concept Inventory (FCI) [14], the Colorado Learning Attitudes about Science Survey (CLASS) [15], or similar assessments, and yet go beyond them too, trying to connect conceptual understanding to perceptual expertise in a given area. It would also serve as feedback to instructors about what concepts may require better explanations or learning activities to engage student learning in the future.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. EC-1240294 and supported in part by the Chancellor's Award from the Center for STEM Learning. Thanks to Garrison Vigil for assistance with data collection and image processing. Thanks to Krystin Corby, Shaina Martis, and other assistants of the Curran lab for guiding many of the participants through the experiment.

References

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

Annual Conference & Exposition, 2004, p. 11.

[2] K. Goodman, J. Hertzberg, T. Curran, and N. D. Finkelstein, "Expanding Perception : How Students ' See ' Fluids (#12169)," in *ASEE Annual Conference and Exposition, Conference Proceedings*, 2015.

[3] J. Hertzberg, B. R. Leppek, and K. E. Gray, "Art for the Sake of Improving Attitudes towards Engineering," *Am. Soc. Eng. Educ.*, 2012.

[4] K. Goodman, J. Hertzberg, and N. Finkelstein, "Aesthetics and Expanding Perception in Fluid Physics," in *Frontiers in Education*, 2015, pp. 1747–1751.

[5] J. P. Mestre, A. Cheville, and G. L. Herman, "Promoting DBER-Cognitive Psychology Collaborations in STEM Education," *J. Eng. Educ.*, vol. 107, no. 1, pp. 5–10, 2018.

[6] M. A. McDaniel *et al.*, "Maximizing undergraduate STEM learning : Promoting research at the intersection of cognitive psychology and discipline-based education research," 2017.

[7] K. Goodman, J. Hertzberg, T. Curran, and E. E. Austin, "Visual Expertise in Fluid Flows: Uncovering a Link Between Conceptual and Perceptual Expertise," *(in submission)*, 2019.

[8] L. S. Scott, J. W. Tanaka, D. L. Sheinberg, and T. Curran, "A reevaluation of the electrophysiological correlates of expert object processing.," *J. Cogn. Neurosci.*, vol. 18, no. 9, pp. 1453–1465, 2006.

[9] J. W. Tanaka and T. Curran, "A neural basis for expert object recognition," *Psychol. Sci.*, vol. 12, no. 1, pp. 43–47, Jan. 2001.

[10] I. Gauthier, T. Curran, K. M. Curby, and D. Collins, "Perceptual interference supports a non-modular account of face processing.," *Nat. Neurosci.*, vol. 6, no. 4, pp. 428–432, Apr. 2003.

[11] C. M. Bukach, W. S. Phillips, and I. Gauthier, "Limits of generalization between categories and implications for theories of category specificity," *Atten. Percept. Psychophys.*, vol. 72, no. 7, pp. 1865–1874, 2010.

[12] N. Sharp, "A Simple Cylinder in a Steady Flow Creates," *FYFluidDynamics.com*, 2014. [Online]. Available: http://fyfluiddynamics.com/post/78446109850/a-simple-cylinder-in-a-steady-flow-creates-a.

[13] J. W. Tanaka, T. Curran, and D. L. Sheinberg, "The training and transfer of real world perceptual expertise," *Psychol. Sci.*, vol. 16, no. 2, pp. 145–151, 2005.

[14] R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.*, vol. 66, no. 1, p. 64, 1998.

[15] W. K. Adams, K. K. Perkins, M. Dubson, N. D. Finkelstein, and C. E. Wieman, "The design and validation of the Colorado Learning Attitudes about Science Survey," in *Physics Education Research Conference*, 2004, pp. 45–49.