

Art for the Sake of Improving Attitudes towards Engineering

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Abstract

Since 2003, a course that incorporates art and engineering has been offered to mixed teams of engineering and fine arts photography and video students at the University of Colorado, Boulder. The course is focused on the art and physics of flow visualization. The course is largely technical, including imaging techniques, optics, some fluid physics and specific flow visualization techniques. Student work for the course consists entirely of open-ended assignments to create and document aesthetic images of fluid flows. A survey instrument is being developed that explores student perceptions of and attitude towards fluid physics or other engineering topics such as design. It has been administered to students in the flow visualization course, in a traditional junior level fluid mechanics course, in a course on design and in an upper division technical elective on sustainable energy as a control. Survey results indicate that the students in the flow visualization course, after a semester of making images for art's sake, emerge believing that fluid mechanics is more important to themselves as engineers and to society, i.e. they have a positive shift in affect. The students in the traditional fluids course which is packed with real-life engineering examples exhibit a negative shift in attitude, which is typical of other technical courses. The use of photography in improving student perceptions is being extended to a course on perception of design. Although many course elements were identical to the Flow Visualization course, including an emphasis on aesthetics, results from the attitudes survey towards design indicate no shift in attitude, nor was there an attitude shift seen in the upper division sustainable energy elective. These preliminary results suggest that whether a course is elective as opposed to required may have an impact on the maintenance of attitudes through the semester. The observed lack of positive shifts in the Perception of Design course indicates that the significant positive shifts seen in the Flow Visualization course are only partly explained by this elective factor.

Introduction

Efforts to bridge the cultural divide between science and art have gained momentum in recent years. One such effort at the University of Colorado, Boulder, is a course on the physics and art of flow visualization. First offered in 2003, the course brings together engineering majors with students from a range of other disciplines; mostly photography students, plus students from art history, film, and journalism. In contrast to

many other art/science courses, the artists do not contribute only art to their joint projects, nor do the engineers contribute only technical assistance. Instead, the engineers are expected to be artists, with aesthetic control over their work, while both the art students and the engineers are expected to preserve the scientific utility of their images of fluid flow by providing accurate documentation of the flow and imaging process. There are several other unusual aspects of this course. All assignments are open-ended: students are not given explicit requirements or instructions to use specific flows or visualization techniques. Instead they are provided with a range of resources and are required to use creativity, guided by their own aesthetic sensibility, to generate their fluid flows and visualization techniques. Grades are de-emphasized by grading based on full completion of all assignments. Constructive feedback is provided by in-class critique sessions. All student work is published on a high-visibility archival website ¹, such that their work becomes a part of their permanent online persona. None of these innovations were research-based at the time; they were assembled based on the instructors' personal values as an empirical experiment.

As hoped, students responded to these challenges with enthusiasm, enjoying their collaborations with those from the other side of the divide, and demonstrating mastery of much of the technical content provided in the course. In two other respects, outcomes from the course have far exceeded expectations. First, the range of physics demonstrated and the quality of images have been worthy of awards and archival publication²⁻⁵. Second, and certainly more importantly, students report that *their perception of the world around them has been broadened to include fluid physics*, in a way that no other course has done. Students write to the instructor years later, enthusing about seeing mixing in a liquid soap dispenser, or vortexes in an unusual cloud. This never happens with students from the same instructor's traditional fluid mechanics courses. Such an impact is the very breath of life to an instructor, and is worth understanding. Imagine what our students would be like if all engineering courses had similar effects. In an effort to begin investigation of this impact, a Fluids Perception (FluPer) survey is being developed.

In 2009, in an attempt to extend the benefits of the Flow Visualization course (FV) to other engineering topics, a new course 'Perception of Design' (PD) was created. Like FV, the emphasis was on open-ended assignments in which students made aesthetic photographic images, in this case of some aspect of design. Like fluid physics, design is pervasive in our manufactured environment, but often goes unnoticed. Every 'thing', including machine parts, consumer products, architecture, any artifact that involves solid or fluid mechanics, has undergone some sort of design process. Good design encompass many aspects, from simple functionality (will it do the job) to structural integrity, manufacturability, cost, material selection, history, environmental impact, sustainability, aesthetics, ergonomics, ethics and safety. Design is central to engineering, and awareness of the multiple, competing criteria that govern the final results of a design process is essential to engineering competence. Based on results from an informal exit survey from FV, PD was initially designed to increase awareness of, and appreciation for, all aspects of design. The course has now been offered three times, with a modified version of the FluPer survey administered pre and post.

The idea that a broadening of perception, of 'eye opening', is important to educating engineers has not received much attention to date. The importance of visual perception in cognitive gains is well established ^{6,7}, as is the importance of graphical information, and improving students' ability to work in a variety of

representations (words, equations, graphs) is an active area of research⁸⁻¹¹. However, the unique impact of FV falls into the *affective* domain. Perception, awareness, noticing, and valuing are latent characteristics included in Bloom's Taxonomy of the Affective Domain¹². In these terms, we hypothesize that the FV course improves students' perception and valuing of fluid physics, although the exact mechanism is as yet unknown. For example, does allowing students to make images for art's sake as opposed to utilitarian purposes result in these improvements? Is interaction between engineering and arts majors a critical component? In order to determine the effect of a specific intervention an appropriate measurement is needed.

Measurements of affect (or 'attitudes', a term used more frequently in the educational psychology community) are more difficult than measurements of cognitive achievements, and fewer validated instruments exist. Several surveys have been developed to study the attitudes of students towards introductory physics and the epistemologies related to learning physics¹³⁻²⁰. Generally, students emerge from introductory physics courses with attitudes that are less like an expert's than when they began the course^{19,20}; this is termed a negative shift in affect. Although including more active engagement techniques can mitigate these negative shifts, only a select few pedagogical techniques that focus explicitly on epistemology have shown positive shifts in affect^{14,18,21}. In engineering education, attitude surveys are increasingly common²²⁻²⁵, although few achieve validity and reliability, and these have not yet seen widespread use in testing interventions²⁴. Many surveys focus on introductory and freshman experiences^{14-16,18-21,26}, while some address attitudes of upper division and graduate students^{22-25,27}. In any case, the affective domain is broad, and attitudinal surveys are generally focused on how students feel about the usefulness of a specific pedagogy or issues of identity. Since none of the existing survey instruments are appropriate for exploring the perceptual shifts we hypothesize, we have continued to develop FluPer, following the Item Response Theory laid out in Wilson²⁸.

This work is also motivated by a desire to explore the importance of creative aesthetics, of making art, in the education of engineers. Until 2000, ABET precluded engineering students from applying any fine art studio course towards their degree. Since then, although allowed under ABET, most engineering programs still do not allow such courses to apply towards a degree except as 'free electives'. This embodies a 'fear of basket weaving courses', i.e. a widely held view by engineering educators that students couldn't possibly benefit significantly from such courses (an attitude also found in mathematics²⁹). We hypothesize that by excluding fine art studio courses we are communicating clearly with our students that artistic creativity is not valued in engineers, and that students who do value artistic creativity had better choose a different major. The net result is that creative students are likely discouraged from engineering, resulting in reduced intellectual diversity in our students, and possibly in reduced gender and cultural diversity as well. Certainly efforts to improve gender balance in Mechanical Engineering in particular have not been successful, despite an emphasis on issues thought to appeal to women such as the importance of M.E. to society. Could our poor recruitment and retention of women be due to other factors such as the perception that M.E. is 'dry' and involves only 'ugly' nuts and bolts? Can the aesthetics of fluid flow be used as a recruiting tool and encourage retention? It is interesting to note that our M.E. department ranks 6th in the nation in female faculty (20%), all of whom are involved in research in some aspect of fluid mechanics. The first time the FV course was offered, when it was an unknown quantity to our students, a disproportionate number of women M.E. students enrolled in it, both graduate and undergraduate. Since then it has been so popular with both male and female students that it fills up immediately, and its

demographics reflect our student population. The hypothesis that women might be influenced by the aesthetics of mechanical engineering is supported by recent work by Cheryan et al,^{30,31} who found that women in stereotypically male environments (containing ‘Star Trek’ posters and soda cans) , either physical or virtual, were much less interested in computer science careers than women in environments that conveyed ‘ambient belonging’, such as water bottles and *art on the walls*.

We summarize our hypotheses as follows.

1. The FV course improves students’ perception and valuing of fluids
2. Incorporating elements of art and aesthetics into engineering courses, including the production of art works, can improve student attitudes towards engineering.

This paper will first describe the Flow Visualization course in more detail, and present some student images from the most recent offering. Details and images from PD will be described next. A description of the development of the FluPer survey will follow and results from FV, PD and two control courses, a traditional junior level Fluid Mechanics (FM) course, and an upper division technical elective on Sustainable Energy will be presented.

Flow visualization course description

The Flow Visualization (FV) course is offered as a technical elective to the engineering students, and is cross listed as studio credit for the fine arts students. The course content is largely technical. The course begins with several overview lectures, where a range of visualized fluid phenomena are introduced. There are four lectures on basic photographic techniques. Emphasis is placed on the quantitative aspects of optics and the interrelationship of spatial and temporal resolution in the measurement of fluid flows. There are six lectures on flow visualization techniques for gas and liquid flows. Basic techniques include adding tracer materials such as dyes, where the interface between the dyed and clear fluid can be seen. Distributed tracers, such as dust in air and rheoscopic fluids are also discussed. Additional techniques include those that utilize the index of refraction (schlieren and shadowgraphy), and surface techniques such as oil smears, temperature sensitive paints and tufts. The fluid dynamics of clouds are addressed in detail in three lectures. Two more lectures survey additional fluid phenomena including turbulence, vortex dynamics, and the use of nondimensional parameters. The art component varies depending on the availability of guest lecturers from the Department of Art and Art History; recently ‘Aesthetics Other Than Beauty’ and ‘Impact of Technology on Art’ have been included. We also discuss ‘what makes an image *art*?’ ‘What makes an image *science*?’ and ‘What digital image processing can be done without compromising the information of the image?’

Some flow and imaging facilities are provided including a small flume, a Hele-Shaw cell, stage fog machines, fish tanks, video lights and a high speed video camera. However, in general students develop their own apparatuses, and provide their own photographic equipment.

Students are given six assignments over the semester. Three assignments are performed as individuals, including two assignments to photograph clouds, and three are done in teams. Each student in a team submits a

unique image or video over which they have complete control. Thus the roles of auteur and assistants are rotated among team members. The teams of around four students are formed by the instructor to distribute backgrounds, skills, equipment and resources across the teams.

Each image submitted must be accompanied by a detailed report, describing the conditions required to reproduce such a flow, or an analysis of the weather physics represented. A discussion of artistic intent and photographic technique are also required. Expectations for the reports vary according to the level and major of the student, and students are given a rubric in the shape of a self-assessment form. At one end of the scale, engineering graduate students (about 1/3 of the students) are expected to produce a publishable short paper, complete with literature survey and a sophisticated discussion of the fluid physics involved. At the other end of the scale, the Fine Arts photography and video students (5% to 20% of the class) are primarily expected to document their work. When reporting on cloud images, all students are expected to include an appropriate Skew-T diagram and comment on the relative atmospheric stability that it indicates. A teaching assistant reads the reports and gives brief feedback to the students as to whether these expectations have been met; if not, they are encouraged to resubmit their report.

Students receive feedback during in-class image critiques. For the past two years, students have been asked to bring a laptop to class on critique days so they can enter anonymous comments into discussions within the online course management system as each image is displayed and explained by the artist. Previous efforts to encourage students to critique each other verbally failed amongst the engineers, although the Fine Arts students were comfortable with it. A new system will allow smart phones to be used in addition to laptops. Students seem to be motivated by the quality of the work of their peers, by publication on the course website ¹, which has high visibility (just Google ‘flow visualization’), by national science image competitions, by inclusion in publications about the course and by display of images locally.

Flow Visualization Course Outcome: Student Images from Spring 2011

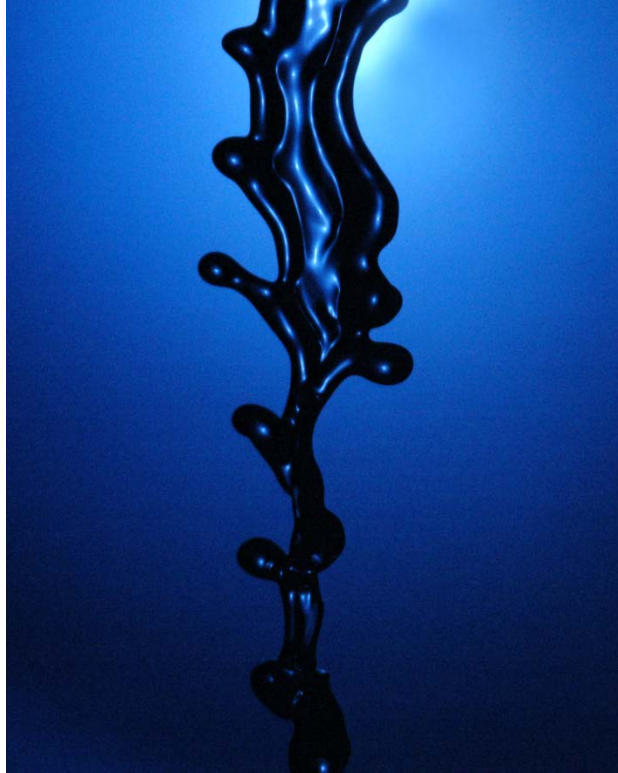
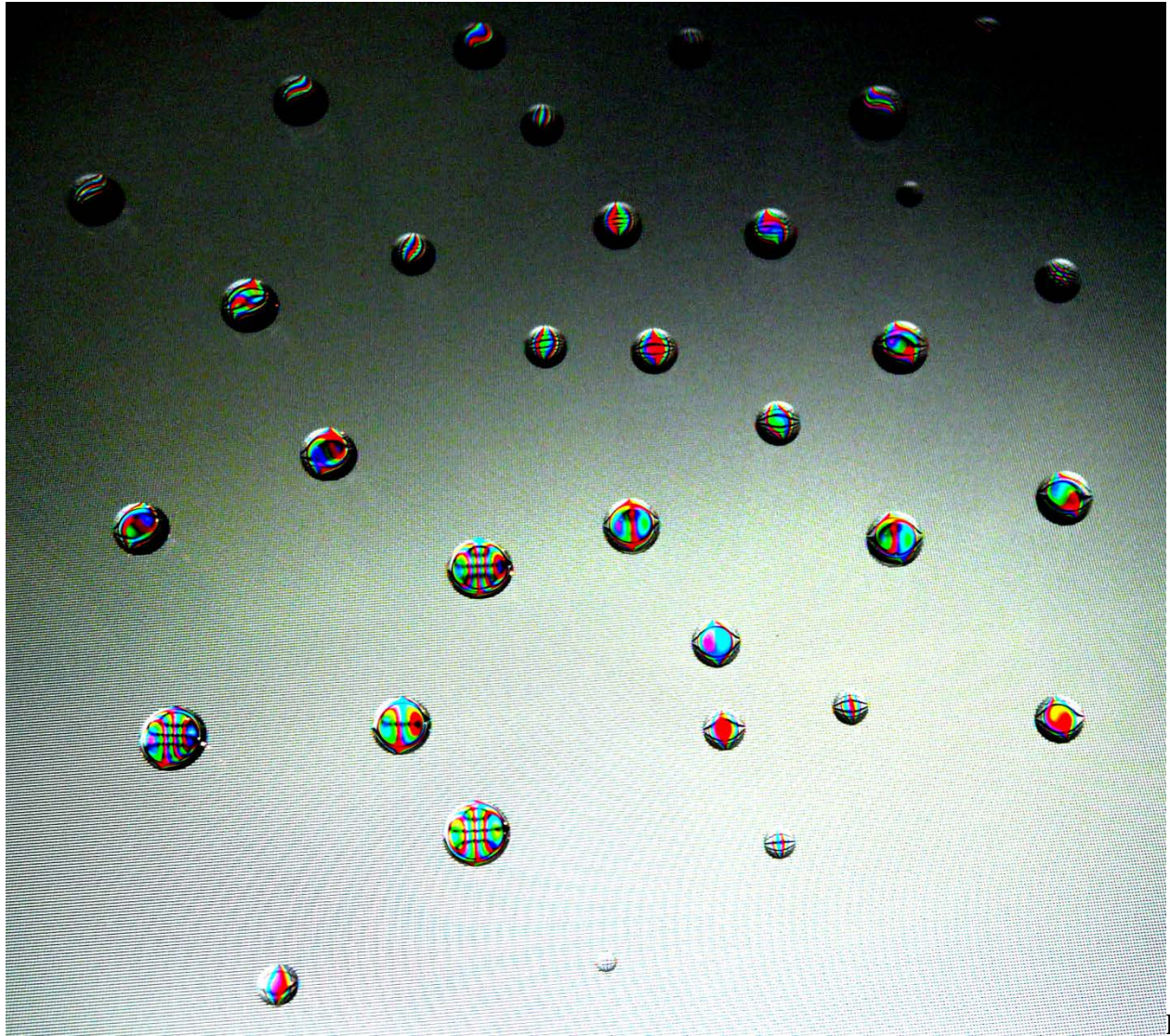


Figure 1: A JP-8 fuel stream from a slit nozzle shows signs of the Rayleigh instability. By Andrew Carter.



Figure

2: Droplets act as lenses, showing pixels on an iPad. By Davis Fogerty.



Figure 3: The wake of a 3 mm rod in dyed milk shows a von Karman vortex street. By Nathan Sheiko, Boris Lemattre, Andrew Beat, John Goblirsch, Gary Velasquez

Figures 1 through 3 are examples of student images from Spring 2011. Additional information about each image is available on the course website¹.

Perception of Design course description

Since Flow Visualization is an unusual course in a number of ways, it is not obvious what the most important aspect is. On an informal exit survey in 2008, students were asked what aspects had the most impact on them. Answers included

- Emphasis on aesthetics vs. utility
- Student choose fluid physics to study
- Freedom from constrained assignments
- Creativity is expected
- Photography context
- Study of clouds
- Critiques

Accordingly, a new course was designed that incorporated these aspects of FV (except the cloud study), but the subject matter was changed to design. Students were given some instruction in photography, and were then asked to make images or videos illustrating a designed product, lead a short class discussion about the

design, and submit a short paper on the critical design aspects. Grading and feedback schemes were similar to FV, and the instructor was the same as FV, with additional design faculty contributing to the critiques. Significant differences from FV include that PD was a one-credit elective, while FV is three. Because of the reduced contact time, after the first two class periods were used for photography instruction, all class time was spent in critiques. Also, students were not put on teams, and no students from outside of engineering were invited. Unlike FV, this course has not become particularly popular; it has not fully filled, averaging 20 students, while FV is always full at up to 50 students, with a wait list.

Perception of Design Course Outcomes: Student Images from Fall 2011



Figure 4: Canning jar by Ball. Image by Alyssa Frank



Figure 5: Clock technologies, by Justin Curtice.

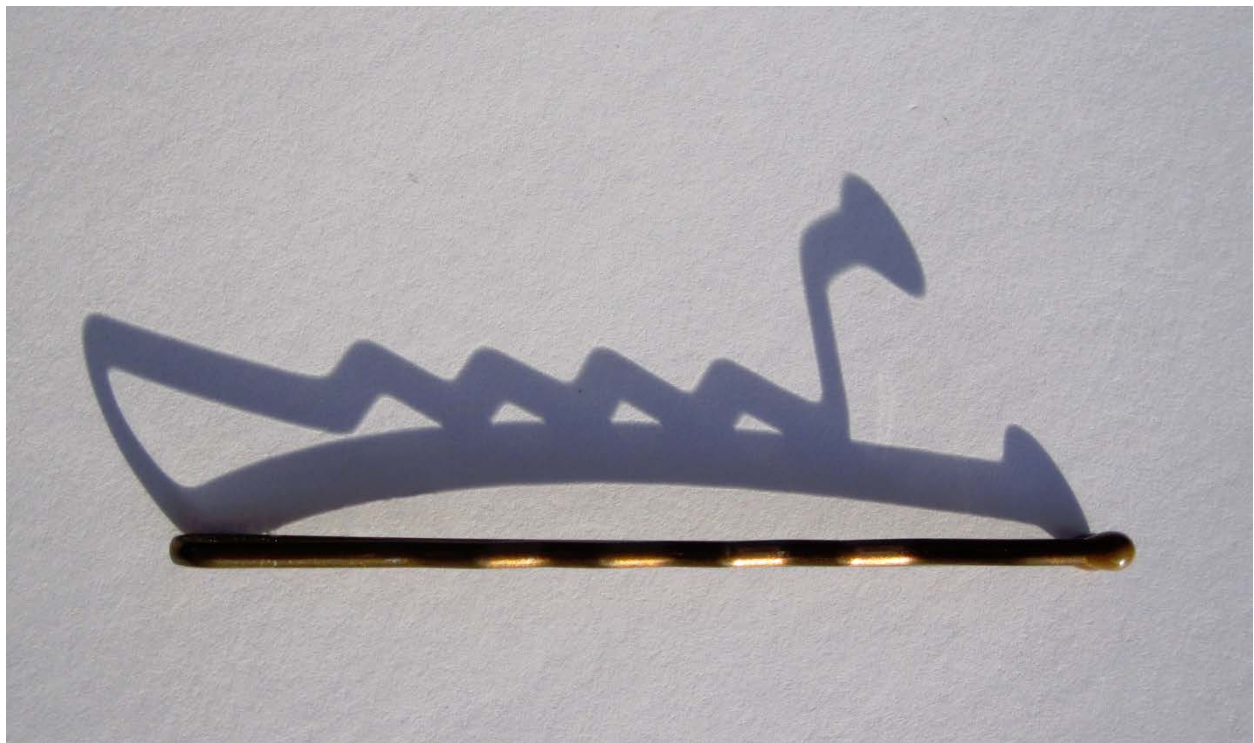


Figure 6: Bobby pin by Haley Schneider.

Although many of the images submitted showed care and creativity, the overall caliber of images in PD seemed lower than in FV. There were a number of poorly executed ‘random object on a table’ photographs. Students also predominantly chose to photograph sports equipment, rather than exploring other aspects of design in the environment.

Midsemester in Fall 2012, the instructor held a group brainstorming session with the class, in an effort to improve enthusiasm for the course. Students chose to form teams, and coordinate their images on a theme. For example, Figure 5 is taken from a group that chose ‘Clocks’ as a theme; each student submitted a different clock image, and the variants in timekeeper design were discussed.

Fluids Perception Survey Development

The Fluids Perception survey (FluPer) is being developed using an item response modeling approach²⁸. This approach is one of several used by the education research community to quantitatively “summarize the responses that people make to express their achievements, attitudes, or personal points of view through instruments such as attitude scales, achievement tests, questionnaires, surveys and psychological scales”³².

The process began with definition of the characteristics to be assessed. In this case, we were first interested in the degree to which respondents notice fluid flows. Another way to phrase this is to ask whether their attention is open to the perception of fluid flows. A second, related dimension is the affective response, meaning do the respondents think fluid flows are beautiful? Are they worth looking at? Interesting? Are they pleasurable to look at? A third dimension is another type of affective response: does the respondent want to study fluid flows, to know more about them, to understand what is being seen or perceived. Taken together we have titled these dimensions the ‘appreciation of fluid flow’ characteristic.

The next step was to define a ‘construct map’ for this characteristic. A construct map represents a continuum, or scale, along which individual respondents can be placed. For example, consider individuals who notice and enjoy fluid flows many times a day: they note the mixing of cream in coffee, admire the beading up of water in an oily pan, marvel at the way wind can carry sleet around the corner of a building, and always look for the sun to light the undersides of clouds as it sets. These individuals represent an extreme appreciation of fluid flow. In contrast, the individual who perceives a puddle with an oily sheen simply as an obstacle to be avoided, who is bored watching waves crash on a beach, and never glances inside Laundromat machines would represent the other extreme of the scale, that of low appreciation of fluid flow. Attitude survey instruments often describe those at the low or entry end of such scales as ‘novices’ while those at the other end of the scale are ‘experts’. We will retain this nomenclature.

Table 1 illustrates the current construct map for FluPer. A map consisting of the first two columns (Awareness of Fluid Flow, and Affective Response to Fluid Flow) was used to design the pilot survey. After a preliminary analysis of the survey results, the concept map was modified as shown, and the results were reanalyzed.

	Awareness of Fluid Flow	Affective Response to Fluid flow	Interest in Studying Fluid Flow
Expert	Always notices fluid flows. Realizes that fluid flow happens all around us in gases, combustion, liquids, etc.	A completely positive response. The person finds the fluid flow very interesting, beautiful, and useful. The person is influenced by any interaction with the topic.	Wants to know all about fluid flows; what creates them, why they behave and look as they do. Enjoys the mathematical formalism of fluid mechanics.
	Notices fluid flows often. Fluid flow happens in nature but involves only liquids	A somewhat positive response. Find much interest, beauty, or usefulness in specific fluid flows.	Wants to know all about fluid flows; what creates them, why they behave and look as they do. Tolerates the mathematical formalism of fluid mechanics.
	Notices fluid flows occasionally. Fluid flow is only created in the lab with a variety of substances	A somewhat positive response. The person may find some interest, beauty, or usefulness in fluid flow	Wants to know about fluid flows; what creates them, why they behave and look as they do, but is only interested in qualitative explanations.
	Fluid flow is only created in the lab with liquids	A neutral, or no response to fluid flow.	Is mildly interested in the physics of fluid flows, and finds them too difficult to study.
	Fluid flow is just a course/ theory that has nothing to do with the real world	A somewhat negative response. It may be considered boring, useless	May be content to admire fluid flows, but isn't curious about them.
Novice	Never thought about fluid flow before	A completely negative response to fluid flow. There is no beauty or interest in the subject. Any interaction with fluid flow does not change their opinion.	Isn't interested in flows or their physics at all

Table 1: Concept map for FluPer.

The FluPer survey has evolved since it was first administered in Fall 2008. Table 2 shows the current versions of the common Likert scale items. Items on the survey were chosen for having a range of difficulty, from multiple choice questions requiring little thought, to essay questions. Questions were also designed to elicit a range of responses, analogous to choosing an appropriate gain and offset in an electrical measurement. Some modifications were made to ensure a range of responses. For example, students were offered a range of frequencies for the

question ‘How often do you notice fluid flows’, but most students consistently chose the highest frequency, essentially saturating the response. The question was modified to ‘How often do you notice and think about fluid flows’ and higher frequencies were offered as well. The first nine questions were designed to be similar across all courses for the sake of comparison. During the semesters Fall 2008 for Fluid Mechanics and Spring 2009 for Flow Vis, Items 1 and 2 were not asked and Item 5 was phrased as “Studying fluids is useful.” In subsequent years the words “to me as an engineer” were added. The question “Visualizations of fluids are fun” was only added in Fall 2011. Also in Fall 2011 an effort to validate the survey via a series of interviews with students was begun; the results have already resulted in planned changes to the survey. Details of the interviews are presented in the next section.

	Flow Vis/Fluid Mechanics	Perception of Design	Sustainable Energy
1	I want to study fluids.	I want to study design.	I want to study sustainable energy.
2	The study of fluids is useful to society.	The study of design is useful to society.	The study of sustainable energy is useful to society.
3	Visualizations of fluid flows are very beautiful.	Visualizations of fluid flows are very beautiful.	Sustainable energy technologies are very beautiful.
4	Fluid flow is interesting.	Design is interesting.	Sustainable energy is interesting.
5	Studying fluids is useful (to me, as an engineer).	Studying design is useful (to me, as an engineer).	Studying sustainable energy is useful to me, as an engineer.
6	I can study fluids.	I can study design.	I can study sustainable energy.
7	I expect this to be/This was a difficult course.	I expect this to be/This was a difficult course.	I expect this to be/This was a difficult course.
8	I expect this to be/This was a fun course.	I expect this to be/This was a fun course.	I expect this to be/This was a fun course.
9	How often do you notice and think about fluid flows?	How often do you both notice and think about design?	How often do you notice or assess the sustainability of a design or choice?
	Visualizations of fluids are fun.	I can do design.	Sustainable energy is fun.
			Seeing sustainable energy in the world inspires me.
			Sustainable energy moves me emotionally.

Table 1: Survey Likert questions

Course	Fall 2008	Spring 2009	Fall 2009	Spring 2009	Fall 2010	Spring 2010	Fall 2011
Flow Vis (FV)		✓		✓		✓	
Fluid Mechanics (FM)	✓		✓		✓		✓
Perception of Design (PD)			✓		✓		✓
Sustainable Energy (SE)							✓

Table 3: Semesters of FluPer survey data available for each course.

All FV, FM and PD courses were taught by the same instructor, Jean Hertzberg, with the exception of FM in Fall 2009. The FM course covered traditional content in Fluid Mechanics. Lectures were relatively interactive, with three to seven clicker questions and around three small group conceptual problems per class. Care was taken to provide real-world context for homework problems and minimize abstract problems. Each lecture started with a presentation of a “Flow Vis of the Day” image or video. In Fall 2011 a “Contemporary Fluids Issue of the Day” was added as well. Sustainable Energy is a traditional mathematics-oriented problem-solving elective course that focuses on a fluids-related topic, and was used as a control to see if the positive shift in attitude was common in upper division technical electives.

Surveys were administered online during the first and last weeks of the semester. Students were given a few homework points for taking the survey, but they had the option to decline the survey by sending an email to the teaching assistant, and still receive credit. Personal identifying data is not collected; students are asked for their first pet and first home street names in order to match their responses pre to post. All students in the four courses, including the art students, were asked to take the surveys. Demographic data, including gender, major, and grad/undergrad status was collected.

FluPer survey data analysis methods

Data was checked to see if pooling between years was warranted. F-tests and T-tests were performed with an α -value of 0.05 between every combination of years within each class. Reported p-values determined whether the years have significantly different results. If the p-value for a given question between any two years was less than 0.05, then the years were significantly different.

A p-value greater than 0.05 was desired because it indicates that a class answers a question consistently from year to year. Any question that had p-values greater than 0.05 across all years was pooled. If a question had a p-value of less than 0.05 between any two years, all years were analyzed individually. Thus for some questions, the data from all years was pooled and for some questions the data was analyzed separately for each year. Pooling was not applicable for Sustainable Energy because the survey was only administered for one semester.

The mean difference was calculated from the difference of average pre-class and post-class. Statistics on averages of individual student shifts are not yet complete.

$$\text{mean difference} = \mu_{pre} - \mu_{post}$$

For questions that were pooled across years, pre and post averages were calculated from all available years.

F-tests and T-tests were performed with an α -value of 0.05 between pre and post. If the p-value for a given question between pre and post was less than 0.05, the shift was considered significant.

FluPer validation methods

In Fall 2011 a series of interviews was conducted to validate the existing data from FluPer Surveys. The interviews aimed to ensure that the respondents were interpreting the items the way the authors intended and also that their responses reflect their true feelings and thoughts. The interviews also aimed to address the issue of why certain questions are somewhat saturated toward the positive response.

Validation interview methods were based on guidelines in ³³. Interviews were done in an informal think aloud format. The FluPer Survey questions served as a guide for the interview, though often additional questions were added, or the interviewee was asked to elaborate on an idea. Interviewees were mainly asked to reflect on what they were thinking when they answered each item, or what they thought the question meant. The validation interviews were held in a private study room, and were conducted by an undergraduate research assistant. The atmosphere was intentionally casual, in order to make students feel more comfortable sharing their thoughts and opinions about fluids. Fliers were used for recruitment. Interviewees were compensated \$20 for their time, usually 20 to 30 minutes. IRB approval was obtained for both the surveys and the validation interviews.

Interviews were recorded directly onto a laptop, and transcribed to text to protect respondents' identities. The first interview was transcribed by listening to the audio and typing. This proved far too slow. *Dragon Naturally Speaking 11.5* speech recognition software and headset was purchased (\$99) to expedite subsequent transcriptions. Because the software has to be trained to recognize specific voices, it could not be used to transcribe interviews directly. Rather, interview recordings were played back on headphones of the headset and the transcriber repeated what was heard into the microphone of the headset. For increased speed, it was necessary that the interview playback volume was loud enough that the transcriber could hear the recording over her own voice. This was achievable when an external microphone was used for the original recording, but the gain from the built-in microphone was insufficient. Thus far, four interviews have been conducted. All interviewees have been Fluid Mechanics students who were

currently taking the class. Six more interviews will be conducted, recruited from current FV students.

Results:

Conditional Pooling

Questions that had p-values greater than 0.05 between all years of available data were pooled.

For Fluid Mechanics, data was pooled from Fall semesters of 2008, 2009, 2010, and 2011 for the questions, “Visualizations of fluid flow are very beautiful,” and “Studying fluids is useful to me as an engineer,” because they had a p-value greater than 0.05 for all combinations of years. The remaining questions were analyzed individually by year. For Flow Vis, data was pooled from Spring semesters of 2009, 2010, and 2011 for all questions *except* “Visualizations of fluid flow are very beautiful,” and “How often do you notice and think about fluid flow.” These two questions were analyzed individually by year. Variances may have been due to modifications in item wording year to year. For Perception of Design, data was pooled from Fall semesters of 2009, 2010, and 2011 for all questions *except* “I expect this to be/this was a difficult course.” This question was analyzed individually by year. For Sustainable Energy, pooling was not applicable because only one semester of data was available.

Pre-Post Shifts

The following bar graphs show the mean shift calculated for each question for each of the survey formats: Flow Vis and Fluid Mechanics (Figure 7), Perception of Design (Figure 8), and Sustainable Energy (Figure 9). Because conditional pooling was applied, some questions have multiple bars representing multiple years of data, and some questions have only a single bar representing the average of all available years of data. Statistically significant shifts are indicated by saturated color.

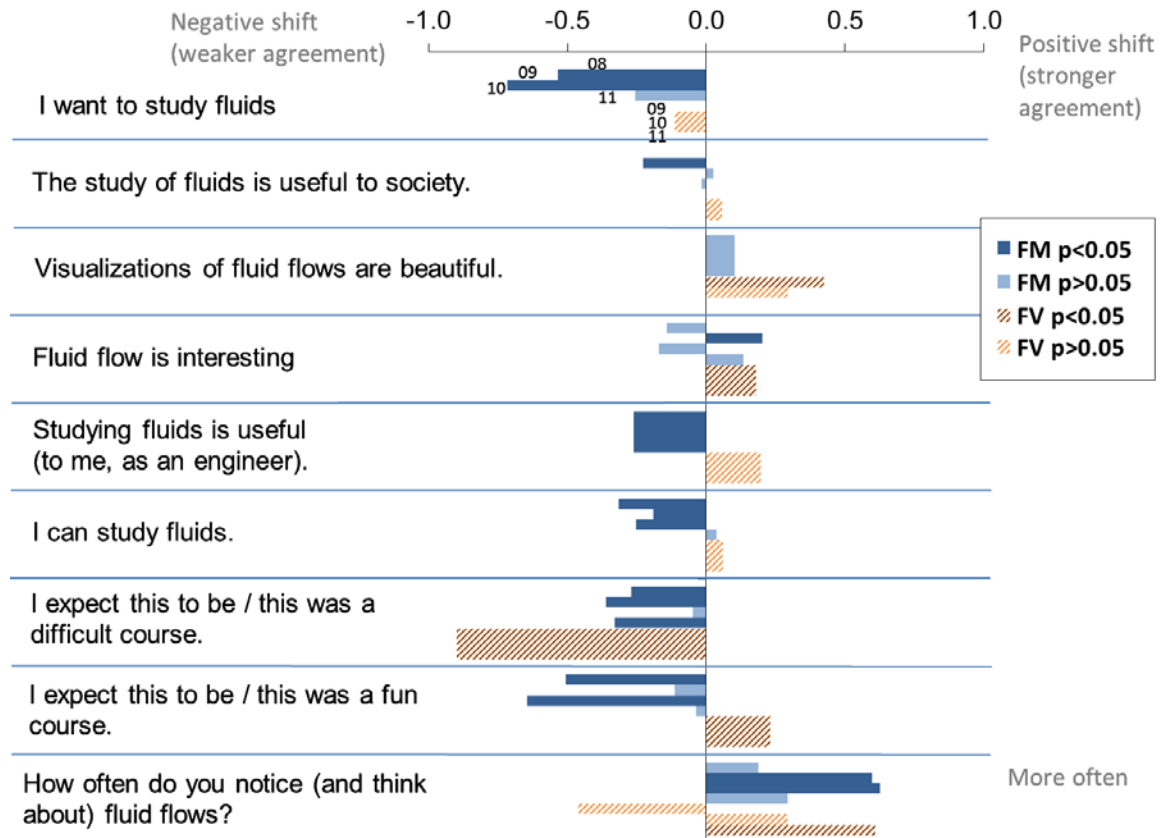


Figure 7: Fluid Mechanics and Flow Vis Pre-Post shifts with conditional pooling. Dark bars represent statistical significance. Where only a single bar is shown, the data were pooled.

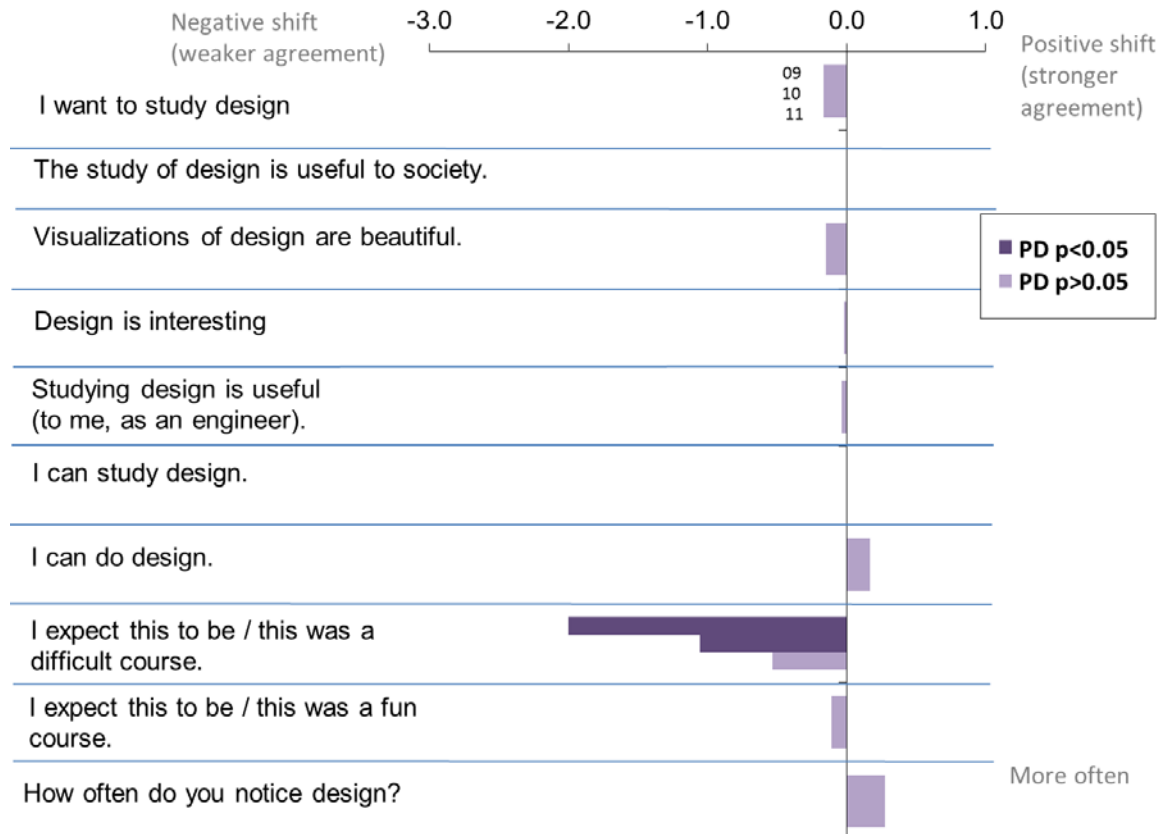


Figure 8: Perception of Design Pre-Post shifts with conditional pooling. Dark bars represent statistical significance. Where only a single bar is shown, the data were pooled.

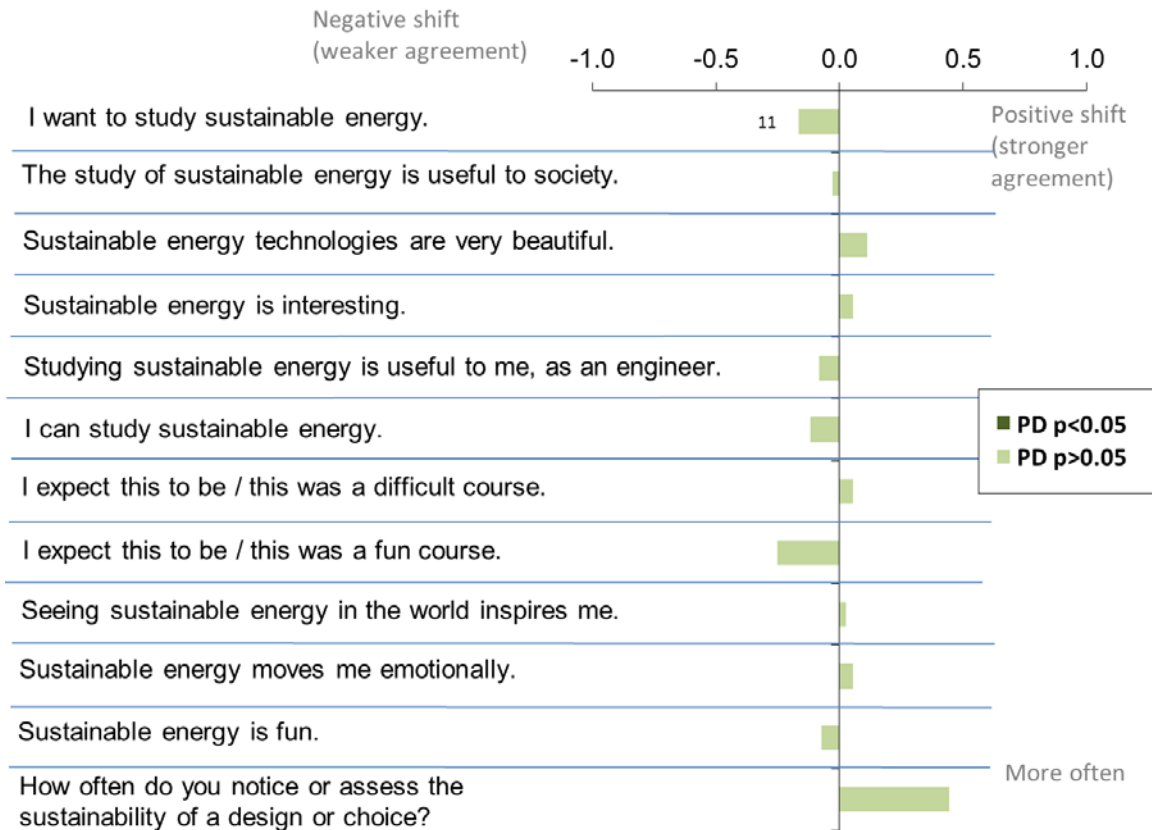


Figure 9: Sustainable Energy Pre-Post shifts. Dark bars represent statistical significance. Pooling was not applicable.

Histograms/Saturation

Saturation of particular items can cause error. When responses are saturated toward completely agree, positive shifts cannot be seen because there is no choice higher than “completely agree.” Below are histograms of responses for a few representative items from the most recent offering of each course, showing the level of saturation.

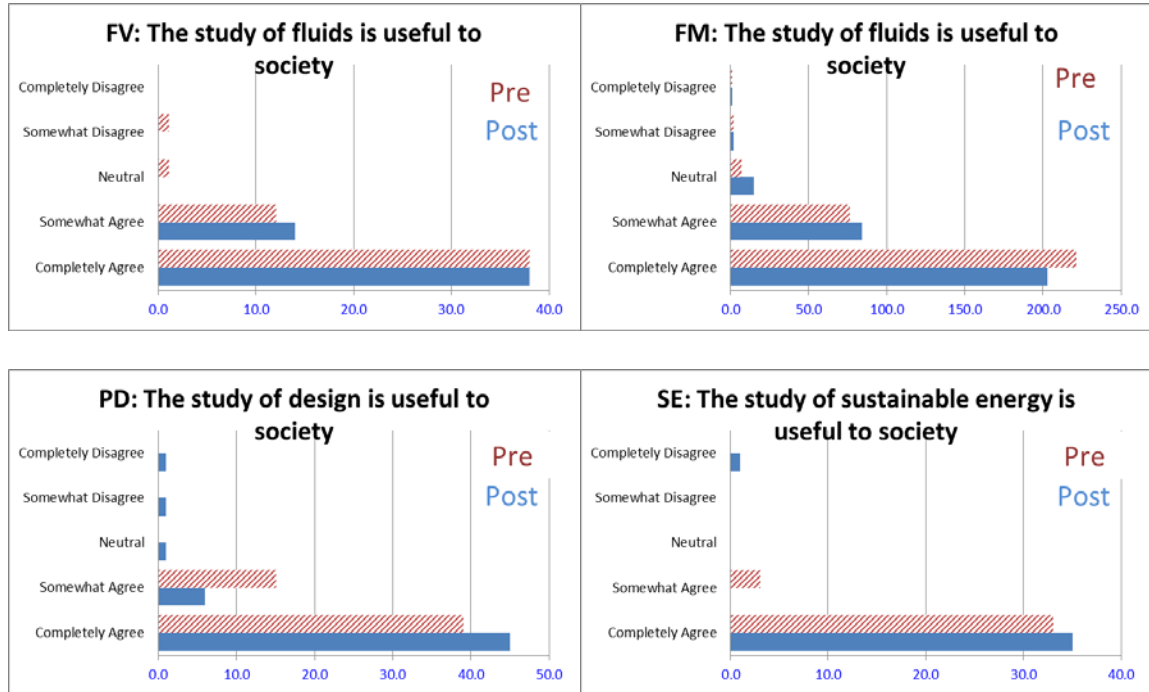


Figure 10: “Useful to society.” Saturation of positive opinions in Flow Vis (top left) in contrast with Fluid Mechanics (top right), Perception of Design (bottom left), and Sustainable Energy (bottom right). Histograms are pooled from all available years for each class.

Responses on the subject of “useful to society” were somewhat saturated toward the positive response for all classes. The level of saturation may be responsible for the fact that shifts for all classes were small for this question, and most shifts were not significant.

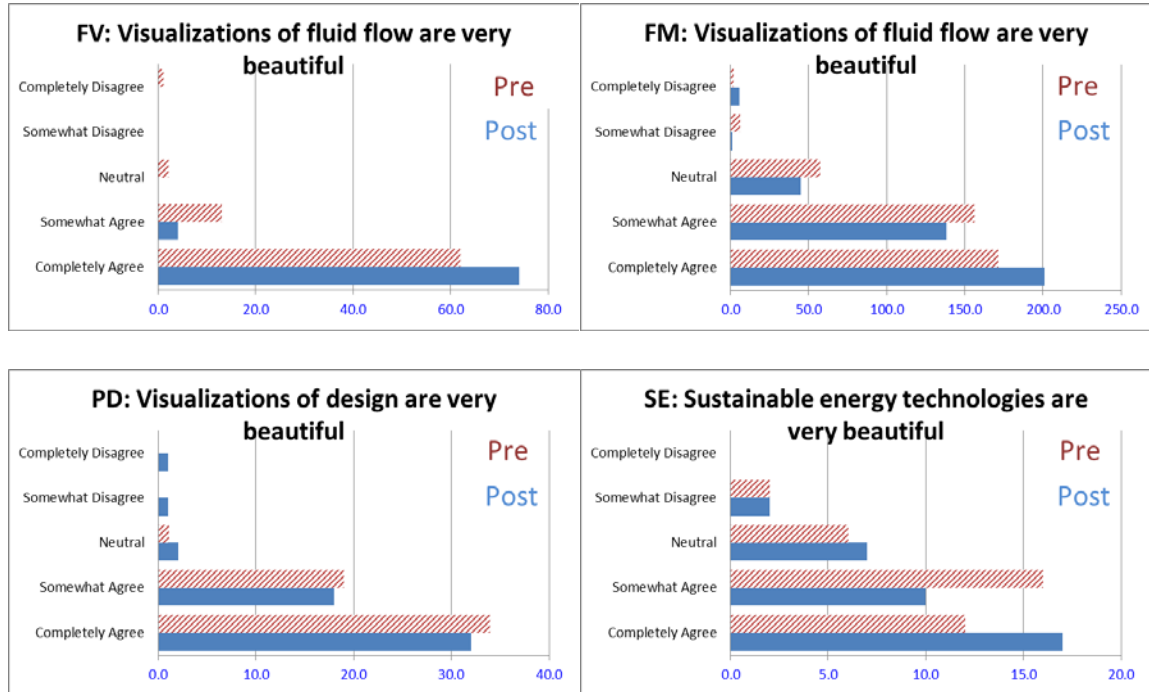


Figure 11: “Beautiful.” Saturation of positive opinions in Flow Vis (top left) in contrast with Fluid Mechanics (top right), Perception of Design (bottom left), and Sustainable Energy (bottom right). Histograms are pooled from all available years for each class.

For the “beautiful” question, the Flow Vis classes had a much higher degree of saturation toward “completely agree” than did any of the other classes. This could introduce error, as the question would not show positive shifts of students who already completely agreed with this statement. In Spring 2011 Flow Vis had a shift of zero; this year the question was almost completely saturated toward “completely agree,” with the exception of one “somewhat agree.”

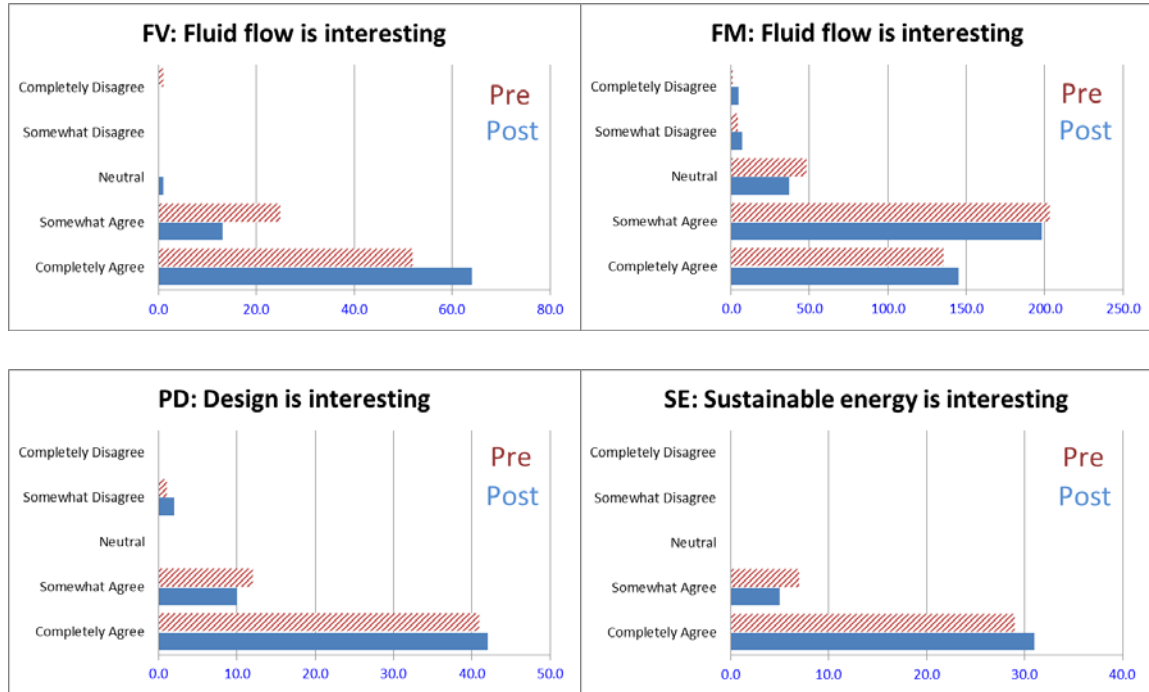


Figure 12: “Interesting.” Saturation of positive opinions in Flow Vis (top left) in contrast with Fluid Mechanics (top right), Perception of Design (bottom left), and Sustainable Energy (bottom right). Histograms are pooled from all available years for each class.

For Flow Vis, Perception of Design, and Sustainable Energy the responses are somewhat saturated toward “completely agree” that the subject is interesting. Fluid Mechanics does not have the same saturation.

Validation Interviews

Some common themes as well as some differences were apparent throughout the interviews. A few discussion topics with select quotations from the interviews are reported below.

I want to study fluids.

A common theme among interviewees was the sentiment of caring about the applications of fluid mechanics, rather than fluid mechanics itself.

I don’t care about fluids for fluids sake; I care about the applications (Student 1).

[Fluid mechanics] is a tool to design more specific things (Student 3).

What does “studying fluids” mean to you?

Students interpret “wanting to study fluids” in different ways, from wanting to apply it in classes to wanting to have a career solely in fluids.

Gain a better understanding of it as it pertains to what you're working on (Student 4).

I want to make studying fluids my whole career, as opposed to just having that be a part of what I do as an engineer (Student 3).

It was proposed that this question be made more explicit. However, further questioning was necessary to determine how students view careers in fluids.

What does a “career in fluids” mean to you?

Students differentiated between a career in purely fluids and applying fluids to their career. All interviewees reported that they thought they would apply fluids to their career but would not want a career in “purely fluids.”

When I think of a career in fluids I think of predominantly CFD modeling (Student 4)

I imagine careers in fluids to be more related to architectural or civil engineering, like HVAC systems (Student 3).

Purely about fluids (Student 3).

To make the question “I want to study fluids” more explicit, a question will be added which asks students to rank their interest in studying fluids on a continuum: “I want to avoid fluids at all costs in the future,” “I would prefer not to use fluids in the future, but if I have to I will,” “I okay with using fluids in my future,” “I am interested in applying fluids to my future career,” “I am interested in a career that is predominantly focused on fluids.” The specific wording for this question was inspired by interviewees’ comments. The question “I want to study fluids” will be kept, however, to allow for relating to past years’ surveys.

What type of flow visualization appeals to you?

Different Flow Visualizations appeal to different students.

The abstract visualizations ... are more ... beautiful... or graceful; there's a lot of smoothness; it's almost relaxing (Student 2).

Having different colors, or if you inject dyes, and you can distinctly see one part of the screen versus the other, I think that can be beautiful (Student 3).

I don't like the ones with the stark contrast where it's very obviously it's this dye injected in this fluid... I like the real world ones a little bit better (Student 4).

What does aesthetics mean?

Although different students had different specific definitions of aesthetics, similar themes appeared. On a visual level, students mentioned *“Pretty colors or a particularly interesting pattern,” (Student 1)*. *“Contrasting colors and brightness,” (Student 4)*. *“Swirls and ... different colors,” (Student 3)*. On an emotional level people mentioned, *“It brings back fond memories and triggers good feelings inside me,” (Student 5)* *“Emotionally pleasing,” (Student 4)* and *“exciting to look at” (Student 2)*.

So even though different flow visualizations appeal to different people, respondents are thinking and feeling similar things when they agree with the statement that “visualizations of fluid flows are beautiful.”

What does interesting mean to you?

The reason this question is saturated is likely because it is so open ended. Students have different interpretations of what is interesting – looking at it, studying it, applying it, etc. However, it is not clear how to improve this question.

Looking at fluids is interesting but also ... looking at the effect of it and what the study of it can do and what the application is, is very interesting (Student 2).

I think it's interesting ... because it is practical (Student 1).

Fluids are really interesting, like how a river is pouring over a rock ...it's really chaotic, and so that seems strange to me, and it seems interesting to me. And that's kind of how I take it to mean, is that not necessarily beneficial and not beneficial, but it kind of captivates me for a minute, and that's what is interesting about it (Student 4).

Studying fluids is useful to me as an engineer.

In response to this question, one student (Student 4) mentioned how fluids applied to his research. Another student mentioned that fluids *“will help me in my engineering career”* (Student 3).

This provides validation that respondents are thinking in similar ways to each other, and that coincides with the intent of the question.

Visualizations of fluid flow are fun. What does “fun” mean to you?

In Fall 2011, a question a new question was asked: “Visualizations of fluid flow are fun.” Students have very different interpretations of what the question means.

Seeing the applications is interesting, um, to me it's not particularly fun (Student 1).

I guess I connected the word fun with things more like social things... Something that I would do...for an hour or two (Student 2).

I think what fun really is, is if you set goals for yourself, and then you achieve them. And so I don't think flow visualization really involves setting goals for yourself, I mean you can observe and admire (Student 3).

I took it to mean that they're fun to do or to perform or fun to capture, and so in that case I can see it being really fun (Student 4).

Clearly, different students have different interpretations of what the question means. To understand students' opinions better, this question will be separated for future years into "I think that making or capturing images of flow visualizations is fun" for Flow Vis and "I think solving fluids problems is fun" for Fluid Mechanics. These questions are meant to analyze how students enjoy the active part of the class. An additional question, "I think that looking at flow visualizations is fun" will be added for both classes.

How often do you both notice and think about fluid flow?

One of the interviewees thought that this question included thinking about fluids in the context of homework.

I think you'd find that a difference between in a fluids class now, because in the course you have to think about it several times a week, at least twice with homework (Student 1).

The wording of this question should therefore be changed for future classes to, "how often do you both notice and think about fluid flow *outside of classwork*" to avoid confusion.

The interviews also sought to determine what students meant when they reported noticing fluid flows with high frequency, such as every day. Are they reporting how often they think critically about or respond emotionally to fluid flow? Or do they just reporting how often they see fluids? From the interviews thus far it seems as though people are reporting how often they not only see fluids, but internalize them in some way, whether that be stopping to admire the beauty or thinking about the physics.

I notice them several times a day whether consciously know that I see them; that's probably once or twice a day where I actually think, wow that's really cool (Student 4).

If I see smoke coming out of the chimney or something I might start to think about velocity versus pressure (Student 3).

I think one thing that goes through my mind constantly when I see fluids is, 'how can you calculate that?' (Student 2).

[I see a] woman passing by in a convertible and I think, 'well, do I have a better streamline than you?' (Student 1).

Discussion

Overall, Flow Vis survey respondents showed positive attitude shifts, while Fluid Mechanics survey respondents generally showed negative shifts, as is common in required introductory science courses^{19,20,35,36}. Figure 7 shows that FV had a greater positive shift than FM with a significance of 0.05 for the questions, “I want to study fluids,” “The study of fluids is useful to society,” “Visualizations of fluid flow are beautiful,” “Fluid flow is interesting,” “Studying fluids is useful to me as an engineer,” “I can study fluids,” and “I expect this to be a fun course.” Thus FV students demonstrated more expert-like attitudes towards fluids after spending a semester making art for art’s sake than did the FM students who spent an entire semester solving engineering problems with real-world contexts. Surprisingly, FM students responded that the class increased how often they notice fluids more so than FV did. However, validation interviews showed that this could be because some students are interpreting the question to include class time and homework. As a result, this question’s wording will be changed for future semesters.

Shifts were more positive for elective classes than the required class. Figures 7, 8 and 9 show that Fluid Mechanics, an upper division required course, showed significant negative shifts, while FV, PD and SE, all elective courses, showed zero or positive shifts. This suggests that in elective courses, where students have presumably chosen the course because of an *a priori* interest, whatever generally expert-like attitudes the students enter with are at least maintained through the semester. Saturation effects may be masking positive shifts. No similar study of attitudes in required vs. elective courses was found during our literature search.

It appears that the significant positive shifts of Flow Vis are not shared by the other elective classes, PD and SE, particularly for the items, “Useful to society,” “Beautiful,” “Interesting,” “Useful to me as an engineer,” “I can study,” “I expect this to be a fun course.” However, the greater positive shifts of Flow Vis were only significant with α of 0.05 for the items “Beautiful,” “Interesting,” and “I expect this to be a fun course.” It seems that the positive shifts in attitude from Flow Vis are not merely a result of it being an *elective* course; some other aspect of its unusual content or pedagogy is responsible. PD shared some aspects with FV: an emphasis on creative photography, a pervasive topic, and similar grading and feedback. However, since PD was a one-credit course, students may not have taken it as seriously as FV or SE. Another missing element is a mix of students on teams, including graduate students and students from Fine Arts. A modified version of PD is being considered, which would have such a student mix and be three credits. Another consideration is the level of creativity involved. FV students

create the fluid phenomena that they photograph, while PD students are only recording the products of commercial designs. The PD survey contained essay questions that may illuminate this issue; analysis is ongoing.

Surprisingly, PD did not have significantly more positive shifts than SE in any item. In fact, Figures 8 and 9 show that PD appeared to show slightly more negative shifts than SE in the areas of “Beautiful,” “Interesting,” “Useful to me as an engineer,” and “How often do you notice?” In Figures 8 and 9, both courses showed similar small shifts that were not statistically significant. Figures 10, 11, and 12 show that saturation toward the positive attitude was not responsible for causing the small shifts in PD, but saturation may have been responsible in SE. Again, the similarity of PD responses to SE responses implies that the element of making and explaining aesthetic images is not solely responsible for creating positive attitude shift in the FV course. This is also supported by Figure 11, which shows that FV responses are more saturated than PD in appreciation of the beauty of fluids and design respectively. The difference in the two classes’ appreciation of beauty thus indicates that the incorporation of photography and aesthetics alone is not what separates FV from other electives. Rather it may be a combination of other factors such as the creative element of coming up with Flow Vis setups, the design process of making the experiments actually work, the more intensive experience, or the influence of the art students in the class.

Validation Interviews justified changing wording on several questions. “I want to study fluids” will be changed to a question which asks students to rank their interest in studying fluids on a continuum: “I want to avoid fluids at all costs in the future” “I would prefer not to use fluids in the future, but if I have to I will,” “I’m okay with using fluids in my future,” “I am interested in applying fluids to my future career,” or “I am interested in a career that is predominantly focused on fluids.” “Flow Visualizations are fun” will be separated for future years into “I think that making or capturing images of flow visualizations is fun,” for Flow Vis and “I think solving fluids problems is fun” for Fluid Mechanics. An additional question, “I think that looking at flow visualizations is fun,” will be added for both classes. “How often do you both notice and think about fluid flow?” will be changed to “How often do you both notice and think about fluid flow *outside of class?*” These changes will hopefully make the survey more clear to respondents in future semesters. Common themes in interviewees’ responses in other questions validated that students are thinking about the other questions the way they were intended. Validation and reliability efforts will continue.

Conclusion

The Flow Visualization class showed significantly more positive attitude shifts than Fluid Mechanics, Perception of Design, or Sustainable Energy. The required Fluid Mechanics class showed significant negative shifts whereas none of the elective classes did, highlighting the positive influence of elective over required courses. Yet Flow Vis had significant positive shifts

where Perception of Design and Sustainable Energy only showed insignificant zero shifts. Flow Vis is influential to students' affect for reasons beyond the fact that it is an elective. It was surprising that Perception of Design showed such small shifts because it shared a number of unusual aspects with Flow Vis, including the same class structure of making and explaining aesthetic images, and the grading/feedback scheme. We can thus draw no conclusion regarding the hypothesis that an emphasis on art and aesthetics would improve attitudes. Perception of Design may have failed to elicit positive shifts because it was only one credit, or because some other element was missing. It is not yet clear what in the Flow Vis class causes the positive shift. Future work will include studies of whether FV creates visual expertise, and a new image-based survey to investigate students' perceptions of aesthetic vs. utilitarian representations. Determining which elements cause Flow Vis students to have positive attitude shifts will allow for incorporation of those elements into other engineering classes to improve learning goals, and potentially impact recruitment and retention as well.

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