Surely You Must Be Joking, Mr. Twain!

Re-engaging Science Students Through Visual Aesthetics

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Abstract: Researchers have established improved methods for undergraduate science and engineering education, yet these efforts often overlook the personal meaning students find in their work. Institutions of higher learning should support the creation of personal meaning along with content mastery, aspects that the arts include. We argue that STEM educators must work to overcome student perception that content mastery and personal meaning sit at odds. We provide an example of a technical course that achieves these goals and provide evidence that it is possible to foster connection while developing content mastery.

"Subject: Cool Flow Vis

Hey Professor Hertzberg,

I took Flow Vis [the course] about a year ago and it was a great class. Now every time I see cool fluid phenomenon in real life, I think about you and that class, so I thought I'd share this with you! I cracked my phone screen a few weeks ago and over that time, the air has started to creep between two plates in the screen. It's making a pretty neat Hele-Shaw Cell in only one direction instead of the typical radial style that you see.

Thanks for a great class,

David Zilis" [1]

Fig. 1: Image from student email. The cracked mobile phone screen displays a Taylor-Saffman Instability in the form of a Hele-Shaw cell.

Any instructor would enjoy getting an email like this (see Fig. 1), but beyond personal validation, what can we learn from it? Instead of seeing this email as individual feedback, we could see it as characterizing a specific kind of learning, the kind we most want to encourage. We should explore what causes a student, more than a year after a class, to contact an engineering professor with an example of the material he learned with her [2].

This email and image reveal that the student learned the material in a deep, meaningful way. That learning went beyond the shorter-term memory needed to pass exams or even a more durable form of learning that can recall concepts when prompted years later. This student email is evidence that he had a *transformative experience* [3]. This construct, which identifies certain profound learning experiences, grows out of the work of education researchers such as Wong, Pugh and Girod [3--7], who in turn were developing ideas from progressive education pioneer, John Dewey.

Dewey documented that we learn better by experiencing things, rather than only hearing or reading about them, and that we learn better when we connect new experiences to past ones [8]. In separate work, Dewey also detailed art's power to produce profound shifts in perspective for the person experiencing it – whether the artistic form be sculpture, painting, music, dance or literature – calling it *an* experience [9]. Pugh and others have connected these ideas, noting that the same profound shift can occur in the natural world or with scientific ideas. This is what they call the *transformative experience*. Simply put, students should naturally relate course concepts to what they see in the larger world, apply those concepts, and significantly, find personal meaning in that experience. The three indicators of transformative experience are summarized as expansion of perception, motivated use and affective value [10].

The student email demonstrates at least two of these indicators. The student is reporting, voluntarily, that his perception has expanded: the student sees the world differently because of the course content he learned. He perceives fluid phenomena "in real life." He can also name it ("Hele-Shaw Cell") and tell you why it is unusual (it is forming in one direction instead of radially). In addition, his affective value of the experience is shown in multiple ways: by capturing an image, and by sharing that image with his former professor. Seeing fluid phenomena is "cool," and he reflects that he experienced "a great class." Another way to frame this transformative experience would be to call it a moment of *synosia*, defined by Root-Bernstein and Root-Bernstein as a way a knowing that combines rational thought and feelings/sensations [11]. One classic example of this is physicist Richard Feynman's sentiment about experiencing scientific ideas with everyday objects:

> I have a friend who's an artist… he'll hold up a flower and say 'look how beautiful it is,' and I'll agree. Then he says 'I as an artist can see how beautiful this is but you as a scientist take this all apart and it becomes a dull thing,' and I think that he's kind of

> nutty… I see much more about the flower than he sees. I could imagine the cells in there, the complicated actions inside, which also have a beauty…the science knowledge only adds to the excitement, the mystery and the awe of a flower. It only adds. I don't see how it subtracts[12].

Here is the crux of our problem. Not all students reach that expanded perception with a positive affective reaction. We, as professors and practitioners of STEM fields, identify with Feynman's attitude. Yet, for many students, formal education has dissuaded them from this sentiment. If we cannot fathom how increasing students' perception could possibly detract, how can we help students reach a point where they can value, emotionally, that increased perception? Feynman's artist friend is not the only one for whom knowledge induced the conversion of a beautiful experience into a "dull thing." Consider this excerpt from Mark Twain's *Life on the Mississippi* [13], as he describes how aspects of the river went from holding "romance and beauty" to only displaying information pertinent to his job:

> … that slanting mark on the water refers to a bluff reef which is going to kill somebody's steamboat one of these nights, if it keeps on stretching out like that; those tumbling 'boils' show a dissolving bar and a changing channel there; the lines and circles in the slick water over yonder are a warning that that troublesome place is shoaling up dangerously; that silver streak in the shadow of the forest is the 'break' from a new snag, and he has located himself in the very best place he could have found to fish for steamboats…. All the value any feature of [the river] had for me now was the amount of usefulness it could furnish toward compassing the safe piloting of a steamboat…

Many of us discovered the poetry of rivers through Twain's writing. Ironic then, that he also captures the downside of expanded perception. Twain concludes this reflection by noting that other professions likely have the same problem, and finally wonders, "Doesn't he sometimes wonder whether he has gained most or lost most by learning his trade?" Like Twain, students get stuck in a place where their expanded perception is a form of incessant judgment. Here is one student’s response to a recent course survey that asked students to rate their agreement with statements such as “technologies [related to the course] are beautiful” and “[course topic] moves me emotionally.”

> [course topic] does not "move me emotionally" nor do I find it "beautiful." It is a functional tool that enables other technologies, and while I find it awesome, I frankly think that those are inappropriate questions for a survey about a class.

This is only one student’s opinion, and it is somewhat contradictory (isn’t finding a topic to be “awesome” an emotional response?), yet it echoes an interesting problem for those of us attempting to deepen our students’ engagement with the material we teach. On some level, this student believes the coursework should not be emotionally engaging, and we should not think about its beauty or lack thereof. We should not even ask about it.

Despite education reform since Dewey, our institutions have fostered reductionist and de-contextualized learning. Some may argue that we need not attend to what students feel about what they are learning, so long as they learn it. This ignores how emotional engagement influences student persistence [14, 15], and it ignores the excitement scientists often feel for their work. If we design our courses away from viewing our fields with passion, we misrepresent our disciplines. Moreover, we know that ignoring emotional engagement results in physics students who learn, by measures of conceptual and algorithmic mastery, while their beliefs about physics shift to a less expert-like view of the discipline [16--20]. We have physics courses that result in students who are less likely to view physics as connected to the “real” world, while completing physics problems correctly.

Do we, in the structuring of our courses, assignments and exams, drive our students to Twain’s starkly pragmatic view? Or do we encourage a Feynman-like joy in what they now know and can do?

Furthermore, when judgment is foremost in our course design, we encourage a fixed mindset in our students, the notion that intelligence and other talents are set quantities. As Dweck's work on mindsets has demonstrated, this makes every learning task a proof of our worth [21]. This view impedes learning and inclusion of learners, because errors are exclusively points lost, not opportunities to learn from mistakes. Even a single low score is an indicator that the student is "not a science person" and does not belong. This confounds both local [22] and national [23] efforts to broaden STEM participation.

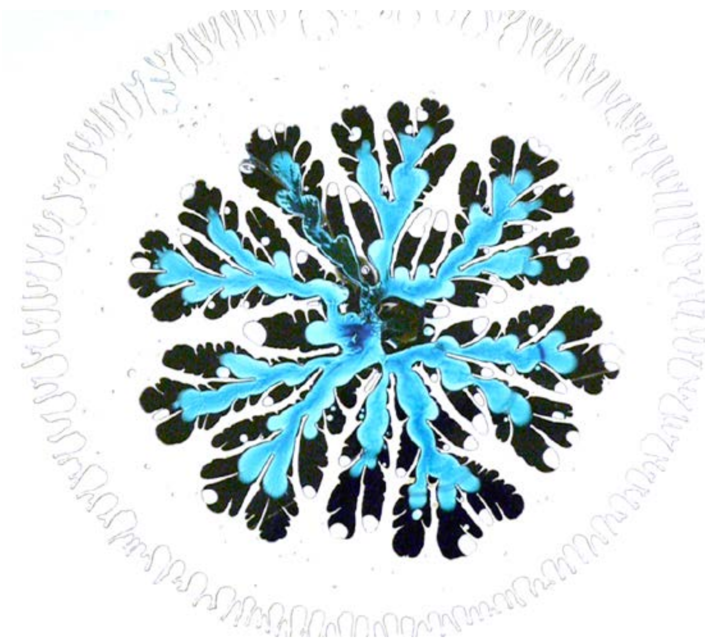

Fig. 2: Student work from Flow Visualization course. Dyed water and air injected into honey produces the Taylor-Saffman instability in a Hele-Shaw cell. This captures the same phenomenon as the student email image. (© Jean Hertzberg; Photographers: Scott Hodges, Alex Unger, Eric Fauble, Zac Rice, 2014).

Once we recognize the need to orient our courses so that students can both expand their perceptions and value that experience, the challenge becomes how to do so. One answer we are studying is introducing a topic with its aesthetic dimension. The opening email was from such a course: Flow Visualization asks students to create images of fluid flows that are both scientifically useful and beautiful, such as Fig. 2 and Fig. 3 [24]. Students present their work in class, and then write papers about the physics involved. This course consistently garners unsolicited comments like those in the opening email. These comments are shared with enjoyment, not annoyance. Since students begin by making aesthetic choices, the course structure scaffolds the expansion of perception via discovery and exploration, perhaps supporting positive affective response [25,26]. Note that the aesthetic dimension of the course does not detract from learning fluid dynamics, but instead complements how students value that knowledge. Students express a deepening understanding of core concepts in the pursuit their aesthetic goals [27].

Fig. 3: Student work from Flow Visualization course. Altocumulus lenticularis (mountain wave clouds) form as air streaming over the Rocky Mountains bounces over Eldora CO, January 20th, 2013 at 1:30pm. Assignments that require capturing existing fluid phenomena, such as clouds, also encourage expanded perception. (© Jean Hertzerg; Photographer: Anna Gilgur, 2013).

The course is cross-listed under fine arts photography and film. A handful of students from these majors take the course each time it is offered. We find that the art students' work influences the engineering students, setting a higher artistic standard for all the students' images [28]. The students express a new appreciation for each other's professional skills, as well as viewing their own work in new ways. The art students describe the scientific writing that accompanies their images as helping them document their creativity and replicate an effect in the future. The engineering students use phrases like "flexible, dynamic space" (unlike their usual "rigid thought process") or "more like storytelling" to describe their work. This research echoes other studies that bring art and STEM students together [29, 30] or utilize methods from the arts to promote creativity in STEM [31--33]. A novel element of this course is that engineering students are expected to create art, and not merely assist artists or exhibit creativity in the service of solely pragmatic goals.

In the classroom, STEM professors rarely acknowledge the beauty, elegance or other aesthetic dimensions of our work beyond the “elegant solution.” These aspects of our professional efforts are virtually never mentioned in our formal assessments, even in surveys for the improvement of courses, not for grading students. This notion, that aesthetics and emotional engagement contribute to learning, is so far removed from students’ current experiences that even asking about emotional or aesthetic reactions to a course draws irritation from students such as the one quoted above. In this sense, we are far removed from the humanities, which traditionally connect more directly to human experience, or the arts, which often seek to elicit engagement. We need to create and sustain these more engaging learning environments throughout higher education [34--37]. Then we need to teach students how and why they should engage [38, 39], since they have been trained by past schooling to disengage [40]. Founding a course on aesthetic experiences germane to their fields can help them reconnect. We must lead with the aesthetic component; it cannot be an afterthought.

Nationally, fewer than 40% of students who intend to major in STEM fields complete STEM degrees, and we have a national goal of improving that figure to 50% [41]. Achieving even this modest goal will require robust support of instructional practices that understand the relationship among affect, aesthetics and learning. Teaching to the test, however rigorous, is not enough. Supporting expanded perception is not enough. Students can “see” relevant content in the world without appreciating it. They may wonder, like Twain, whether they “gained most or lost most” in acquiring their expertise. In contrast, if we encourage students to engage their whole selves – to sense, feel and think in their work - they will be more likely to persist through the rigors of a STEM major, and pursue related careers. They may find, like Feynman, like most of us in the STEM fields, that deepening our knowledge does not subtract, it only adds.

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References and Notes

1. Name, text, and image used with permission.

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