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Constructing a space for developing a rich understanding of science through play

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When we think about the two activities of education and play, we tend to differentiate them more by their purposes, end-points and goals than by their processes. It often seems that people are learning effectively when they are 'playing', and vice versa. But, most would agree that the *point* of play is different from that of learning, while there is more interplay between the two than we initially imagine. Learning is a component of playing, and playing is a component of learning, and both taken together constitute a process of coming to know. They are aspects of *one* epistemology. We want to say that this has something to do with conceptions of what it means to know something.

To illustrate this, we quote from a grant proposal we recently wrote. In that paper we were proposing to change the graduate student experience of electrical engineering by constructing spaces where students would learn through case-based problem solving. To do this, we would construct case studies of multifaceted problems in which students could apply electrical engineering and information technologies.

> As an example of a potential case study, consider the following fish story. Fish play an unexpectedly central role in science and science education at the University of Illinois. Margery Osborne uses fish in science education workshops and classes to enable student participation in alternative, enhanced processes of observation. Students explore the fish with their hands and make 'fish prints' by stamping inked fish on paper. The ink-projections often expose a structure that

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> is not visually apparent and, like ink-blots, draw unrelated artifacts and evoke new understandings from the mind of the observer. Separation of 'true fish character' from the tactile, olfactory and cultural response of the observer is not always easy.
>
> The integration of the experience of science with the science itself is also illuminated by the work of Mark Nelson. Nelson, a member of Beckman's (i.e. the Beckman Laboratory at the University of Illinois at Urbana–Champaign) Neuronal Pattern Analysis group, uses weakly electric fish to study neural mechanisms and information-processing principles involved in active sensory acquisition. Fish of the species *Apteronotus albifrons* use an electrosensory system to locate and capture small prey. Using an infrared dual-camera computer-vision system and computer-simulation techniques, Nelson's lab has characterized the movement strategies used by hunting fish, the electrical characteristics of the prey, and the resulting spatio-temporal patterns of receptor activation due to fish-prey interactions. In studying these and other factors, a stunning range of spatio-temporal information has been obtained, including detailed fish-and-prey motion trajectories, 3-D electric-field properties, and reconstructed electrosensory images on the surface of the fish skin. One graduate student has painstakingly carried out frame-by-frame video-reconstructions of feeding sequences to generate 3D-animations of fish–prey interactions. It is not clear that such advanced technologies can be justified from a purely deductive perspective, but in interviews with the primary researchers it becomes immediately clear that they are critically enabling.

In describing the processes in our classes and laboratories, we are describing an intertwining of learning and play in which both are focal to doing science. The fish explorations that Margery leads her classes through are purposefully playful, but the point of the play is to do something that is scientifically meaningful. The work the graduate students do characterizing the feeding patterns of *Apteronotus albifrons* is time-consuming and difficult, but again central to the science of learning about the fish. And, as pointed out in the paragraph above, the science to be discovered, or the tools needed, are emergent during the inquiry. One could imagine that, if the inquiry didn't unfold into something meaningful, the label 'play' would be applied—whereas it is 'learning' once the activity becomes important. Certainly neither 'play' nor 'learning' requires that the knowledge being uncovered or the knowledge that has been learned and is being put to work is articulated, but this is another point that we want to make. The articulation of the processes and purposes behind learning and play cause the resolution of an apparent dichotomy between the two—that forms Dewey's (1916, 1933, Dewey and Bentley 1949) resolution to this particular dichotomy: learning and playing are reflected on—judged, critiqued through articulation—in the context of a purpose which is experientially based. Dewey argues that this is why science or education should be experientially based, and why both work and play should be components.

In this paper, we describe an attempt to create such a space, where practising teachers can develop a rich understanding of the nature of the scientific process and come to recognize through playful experience that there is an array of 'ways of knowing' in science. To do so, we explore science in the context of the visual arts—looking at, making and discussing images by using a number of different visualization techniques in a comparative and critical manner. We assert that science is playful, multifaceted, multidisciplinary, tentative, and emergent. The notion that neither art nor science have hard definitions or procedures is a difficult concept for people who are not members of either community and who have not experienced their richness and variety in both processes and products. To enable such an understanding, we create a space in which our students 'play' in the terrain of science, reflecting on the nature of science in diverse contexts. Creating such an environment of 'play' also serves to suggest to students that science is at heart creative, and that creativity is engendered in many ways. In play, there is a freedom to engage ideas, actions and things which can otherwise be too frightening and dangerous (for many of them perceive science as both of these things), but we would argue that through play students become empowered in the frightening and dangerous.

This becomes a question concerning ways of knowing—again to cite Dewey, knowing of and knowing how[1]—and also, maybe, the other ways of knowing that might be suggested as we recognize the pluralistic qualities of a discipline. Our question is fundamentally about a conception of education—utilitarian or liberal—or a resolution in which both are brought together in the service of each other.[2] This is one reading of the ideal of progressive education—that through intertwining learning and doing, and thinking about the qualities of that learning and doing, all would be enhanced. The effect would be the development of a critical consciousness that extends beyond the particulars of the learning and problems at hand to more fundamental/foundational assumptions about the 'things' being learned and the 'things' being done with that learning. All this has to do with both what is being learned, how it is being learned, and the context in which it is being learned—with others engaged in the process and sharing insights. We illustrate how we try to do this in our classes with three stories of such teaching. The first is about visiting David's visualization labs. The second concerns learning about fish, and the third is about photographic print-making.

Background to our classes

As we have suggested, in our work with practitioners and students in science and science education we set out purposefully to deconstruct images and definitions of science. To this end, we critically explore artistic means of expression and representation—both making art and examining artforms—in our science classes. We begin by looking for the many similarities and differences between doing art and science, and in their products. Both are dependent upon the choice of procedures and medium. Both rely upon insight and inspiration as well as hard work, determination, and self-discipline. Both are creative acts. They differ (sometimes) in their uses and our perceptions of them. Both are judged under critical standards which seem to stand outside of the artist's or scientist's actual work—standards formulated by both communities of practitioners and of outsiders. We explore these points of comparison and reflect upon the questions 'What is art (science)?', 'What do artists (scientists) do?' These become questions of *visualization*: 'What can be seen using a different medium?' 'How is this related to what we want to see?' These are central questions in both art and science, as are the places where they merge and separate.

In our research together, we engage in ongoing conversations about the integration of the arts into subject-matter teaching.[3] We feel that at a fundamental level both science and art are about '*seeing*'—seeing new things and seeing in new ways. This intersection is the starting point of our teaching, and we combine the science and art in our teaching to create a space in which the divergences and similarities between acts of seeing in the two disciplines illuminate each other. In other words, rather than using the one discipline (e.g. art) to enhance our instruction in science, we use the combination of the two to create a potential space of creative critique. Whilst we argue that different conceptualizations of science as an enterprise alter and shape the educational process, we purposely blur the edges between science and art rather than clarify definitions or differentiate the fields. We do this for two reasons: to cause students to think hard about their (usually) stereotyped definitions of science and art; and to enrich their abilities in a process common to both disciplines, the ability to see.

In our stories, we describe our attempts to create spaces where practising teachers can explore the meanings of the seeing process in the context of developing a rich understanding of the nature of art and science. As we watch our students do this, we come to recognize that there is an array of 'ways of seeing' in science, each of which enables the discovery of different qualities in an object. This in turn causes us to reflect back on the nature of the process and our purposes in engaging in it. In particular, we describe how we explore science in the context of the visual arts.

The creation of the stories

We present three stories of teaching science intertwined with visual art from our classes with practising teachers. These are developed from our own experiences of teaching and reflect a participant–researcher stance to research methodology and data analysis. The vignettes were developed from notes and transcripts of classroom lessons written from audio- and video-taping done over the course of a number of years. This is part of a larger study concerning visualization technologies and involving a theorization of a gender- and culturally sensitive science and science education.[4]

Stories of teaching

First story (narrated by MDO)

In our course this semester, a highlight was our visit to David Brady's visualization labs. Prior to the visit we had done a series of readings and activities concerning the nature of art and science, presenting very different views of what constitutes both, but centring primarily on whether art and science are defined by intrinsic qualities or by their interpretation and labelling by an audience. We also read narratives by artists and scientists describing how they did their work. In class we had been using cameras (traditional film, digital, and digital video) and scanners to take pictures of our own and to manipulate these pictures electronically to address the same set of questions about the nature of art and science in our images.

The purpose of the visit to David's labs was described as 'seeing how scientists and engineers worked with the same cameras and technology we had been experimenting with and to see this in a range of settings': a developed 'show-piece' (the CAVE); a less-developed, experimental site (Argus); and 'toys' or components of the first two (an IR camera and robot). In this way, students would see both the end-product of such work and also the processes the scientists were going through to design and realize their 'products'. In class we had been discussing how there was science in the art of such photographers as Ansel Adams, as well as art in the science of biologists like Edward Wilson and Barbara McClintock. We went to David's labs to look for this. The following narrative is written by David.

> On Wednesday 15 September 1999, Margery Osborne's 'Art and Science' class visited the Photonic Systems group at the Beckman Institute. The visit began in the 4th-floor Tower Room with a 10-minute introduction by me. I talked about how automated imaging tools and hypertext could affect how people 'talk' to each other and described our research along these lines. The course web-page was part of that project and was designed to explore the role of hyperlinks and images in interpersonal communications. The basic idea is that technology makes the cost of images as text low, but that the separation of what one wishes to say (content) from how one wishes to say it (context or control) remains difficult—but that was what our research was about. Following that introduction, the class split into three groups for lab tours.
>
> We showed three labs. One contained a robot, a digital camera hooked to a compact computer and an infrared camera. The second was the CAVE virtual reality facility.[5] The third was the Argus sensor array.[6] Photonic Systems group members led demonstrations in each lab. I circled around and made a few comments, but most of the next 2 hours was directed by Ron Stack, the primary organizer of the visit, and the graduate student tour guides.

At approximately 7 pm, we reassembled in the Tower Room for a brief wrap-up. My impression was that our visitors were most impressed with:

(1) our research group itself and the Beckman Institute facility;
(2) the CAVE; and
(3) the IR camera.

The Beckman Institute is a very interesting academic facility. It is intended to make a national and international statement about how research should be done: as collaborative and cross-disciplinary. To a large extent, the vision underlying the building seems to have come from Arnold Beckman himself, the creator of the Beckman Foundation. The building was proposed in response to a national call from the Foundation. Ultimately, separate institutes were constructed at the California Institute of Technology and the University of Illinois at Urbana–Champaign. Illinois proposed life science and physical science buildings. The Illinois proposals were joined at the suggestion of the Foundation. The building is in some ways bigger than the actual research it contains, and certainly bigger than the petty academic currents that run through it. Since it is a national centre, visitors are correct to see the building itself as important. This can seem strange, however, to daily inhabitants. Whilst the building is grand, it contains many design flaws. Architecture and the reality of space are largely unaddressed by science and technology. Putting people together in a building does not a community make.

We did not show our most abstract projects and computational systems. Of course, Argus is a major project for us, but since it is not yet functional we are rather embarrassed to show it. Nevertheless, it seemed to have been the setting which induced our visitors to remark upon our research team as a team. It seemed that here, where the science/engineering was least complete, what we were doing and how we acted together as a unit was most transparent. This group of people, who could not understand the substance of the science here, felt a sense of how we worked—that for us was unconscious and taken-for-granted. It was interesting to have to articulate our roles and how we work together, and how our relationships are developed and maintained.

The CAVE is an artificial space. It is always popular with visitors, but serves primarily to highlight how difficult it is to escape the everyday world. This group was unexpectedly practical in their demand to know the uses of the CAVE. Specifically, they wanted to know why it was needed. Academic engineering research focuses on ‘prototypes’ and ‘testbeds’, with no immediate role and little long-term feeling that these systems will be directly useful. Nevertheless, these prototypes are critical to imagination and to visions of future technologies. I was surprised that this was not apparent to the teachers, but maybe this again tells something about the environment they come from, where money is tight and every moment and expense must be justified.

> The group was also fascinated by the IR camera. The camera measures thermal radiation and can 'see' heat generated by the human body. Noses are cold, and look cold in IR photographs. The torso is hot, but may be obscured by clothing. IR photographs are purely computational, so somewhat unimpressive without context. But, with an IR picture of themselves they could 'see' something that previously they had only been able to feel. The truth in the image was apparent. This seems in juxtaposition to what was experienced and appreciated in the CAVE. Other than pure enjoyment and amazement at what they saw, the teachers seemed enthralled by the perception that such a space seemed designed to cause them to question what was real, to distrust their own senses—exactly the opposite of the IR camera, which 'proved' their senses were correct.

The visit to David Brady's research group represented an attempt to blur definitions of art and science, in this case by looking at the things that scientists and engineers do, i.e. looking for the art in their science. We observed the making of science, its content, process and subject matter, to enable our ability to 'see' science itself. The exercise is particularly layered because the science done by David's group is about 'seeing'. The technology the group is developing is centrally about enabling the seeing of new things in new ways. The CAVE expands our ability to see and immerse ourselves in that seeing; that is why it is so disorienting. The seeing enabled by the IR camera confirms what we already know. By placing the two groups, the teachers and the engineers together, each representing two communities of practice with their own conventions and traditions and taken-for-granted values and activities, each was able to see new things about the other and about themselves. The teachers commented again and again on the magic of what they saw, and their amazement at the abilities of the engineers. They 'saw' the artistry there.

Second story

During our work with practitioners and students exploring the relationships between art and science, a key activity we do together involves printmaking using abstract shapes, leaves and flowers, fish, and octopi. This activity involves the fundamentals of a 'scientific method'—observation, theorizing, understanding an experimental medium and processes, extrapolation, and experimental design—and it also involves artistry and a sense of aesthetics.

> Having just laid out the newspapers, printers' ink, rice-paper, and plastic gloves on the tables in the centre of the classroom, I (Margery, the instructor for the course) reach into the tubs containing the recently defrosted octopi. I am surrounded by faces registering varying degrees of panic. The class I'm teaching is graduate-level and entitled: 'Inquiry teaching and learning'. There are 16 students, about evenly-mixed between practising teachers and full-time graduate students. Tonight we are launching an inquiry project of our own

on sea life, which we will pursue for the next 8 weeks. Our initial activity is *Gyotaku*, the Japanese technique of fish printing, which we are doing this evening with fish and octopi. Only two students have ever actually seen a real octopus.

I hold the octopus up into the air. Its about two-feet long and rather cold. I explain:

> Okay, you take the octopus and lay it on the newspaper, arrange it however you would like, and then smear the ink all over it. When you think you're ready to make a print, take a piece of the rice paper and press it on the octopus. Try making a couple of prints from each inking.

What I *don't* tell them is why we are doing this. I strongly believe that science is about observing, observing things closely and for a long time, 'looking' long and hard and from as many perspectives as possible. I want people to look and feel the animals, smell them, probe them, manipulate them—in all the ways they can. I want to reduce the distance, to put the animals and the people in as close sensual contact as possible. I need a tool to do this, and print-making is that tool.

The students slowly get up and start to select fish or octopi. I have enough for each to have one. They are clearly squeamish, but this seems to abate pretty rapidly as they start to lay out tentacles and examine them. Putting on the ink they discover the varying textures and mysteries of the hood. They find the eyes, and some, looking at the place the tentacles emanate from, find the beak.

They start to make the prints. The textures become apparent and interesting with the second and third prints for it is then that the differences between hood and tentacles manifest themselves (see figure 1). The students start talking about what they are feeling and seeing, and much conversation is occurring about the effects they are getting and about the beasts themselves. Why do the octopi have the various layers of their hoods? Do they all have eight legs? Is the symmetry inside the hood eight-fold?

Things are getting rather loud. People from other classes stick their heads in to see what we are doing. My students grab their prints and run out into the halls to show their friends. The Dean of the College wanders in and asks me where I bought the octopi. At the end of the evening my students leave clutching their prints, discussing where in town they can get them matted and framed. One of the teachers turns to me and says, 'Would you mind if I do this with my class next week?'

The students, in making these pictures—positioning the animal, applying the ink, placing the paper, looking at the prints and observing the patterns of dark, texture and shape, and finally drawing meaning from the experience—involved themselves in an interplay on many levels between pattern and design, purposeful activity, sensuality, aesthetics, science. The whole became an act of discovery in science and aesthetics. The two were tied together and defined each other, giving each other meanings they would not have had if held separate. Such an activity pushes us to think hard about traditional definitions of science and art, seeing the connections

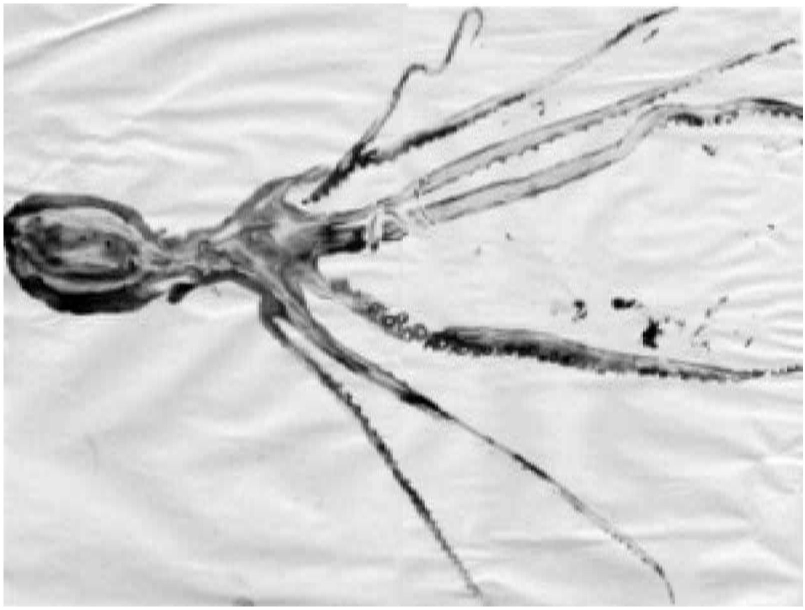

Figure 1. Fish-print of octopus.

between the two, both as conventionally articulated and also in the ‘possible’, the unarticulated. Both the art and the science are emergent because they are intertwined.

Third story

Heather is working three slide projectors simultaneously, over the lens of one she has placed a red film, over the next a green film, over the third a blue film. She moves the red, green and blue lights so they lie on top of each other. The light that results is white. She shows us an image she has created from a photograph taken in Thailand. It is made by separating the colours from her picture, red, green, blue, and creating separate negatives, first in red, then in green, then in blue light. Recombined, the coloured images are transformed, cyan, magenta, yellow. The final image, here shown in figure 2 in black and white, emerges through a textured pool of light.

Heather shows us that when she casts a shadow in red light with her hands the shadow we see is cyan, in green light, magenta. The students are amazed at her explanation of their origin. They cannot seem to understand (although they can recite the ‘rule’) why the combinations are not *combinations*, how white light can be coloured light. The students go to the slide projectors, using their hands to create magical roosters, swans, leaping rabbits, in a rainbow of colours. Their shadow theatre evokes the *wayang kulit*—the traditional puppet shadow theatre of Java and much of Southeast Asia (Thai:

Figure 2. Heather's image.

> *nang talung*). Such performances of the shadow puppet-plays are interpreted in religious or mystical fashion. In them, the ancient animistic rituals of Southeast Asian religions are played out. As in the shadow theatre, the translucent screen becomes heaven, the floor, earth, and the puppets are man the seeker.

Such play in the domain of science is not unlike the play of realities in the literary genre 'magical realism'. According to D'haen (1995), magical realism manifests fundamental qualities of post-modernism. It exhibits or engenders 'self-reflexiveness, metafiction, eclecticism, redundancy, multiplicity, discontinuity, intertextuality, parody, the dissolution of character and narrative instance, the erasure of boundaries, and the destabilization of the reader' (p. 192).

Both D'haen and Ellsworth (1997) point out that magical-realist text speaks from the margins and takes the reader empathetically to that place. It does this through the device of realism; the writing, through its realism, draws the reader into a magical place where the laws of western logic and rationality are suspended. Readers are seduced into thinking from another perspective than their normal one and move into an alternative world from which they can critically reflect back on the realities of the 'normal world'. In her pictures, which were created through the application of printing science, Heather incites mystical, empathetic understandings of another culture, as well as the mysteries of the science. This sense of mystery is itself a challenge to the rational beliefs that we hold of what science understandings should be. Making the pictures involved understanding the technology of the printing technique; understanding the pictures involves an opening of the mind to playful mysteries.

Discussion

These stories are examples of how we attempt to integrate art and science in our classes and, in doing so, enlarge the creative spaces in our teaching. We think they illustrate how merging the two enables our students to see new things, thus enlarging the creative possibilities of doing science. We like to think that such discovery involves a re-enchantment of science in our classrooms so that they become places of wonder and pleasure.[7] We are not unaware, however, of the problematic nature of such procedures and goals.

Since 1989, we have witnessed multiple, high-profile efforts to reform and improve the quality of science instruction in US schools and communities. Much of this has focused on questions of equity, crystallized in the slogan ‘science for all’, and the achievement of ‘high standards’ of science learning or scientific literacy. Linking ‘scientific literacy’ with ‘science for all’ has pushed reformers to stress the importance of making the cultural practices of science as well as science content explicit and accessible, so that all students will have the tools necessary to understand and engage them.

This tension, between achieving a product and engaging in a process, is central to current educational policy debates in general, and in science education in particular. Thus, both of these constructs have come in for a great deal of criticism and we would argue that, in order to give either ideal real substance, teachers need to reflect upon both the complexity of the contexts of public school teaching and the nature of science and scientific knowledge. We concern ourselves here with the second. We believe that teachers need to develop an understanding that science itself is not monolithic; nor is it continually progressive, achieving greater and greater truths. In other words, teachers need a sense of the nature of science and the enterprise of science, not just increased scientific content knowledge.

In our work in science and science education, we have explored how different conceptualizations of science shape teaching and learning (see, e.g. Osborne 1998). In particular, our research has looked closely at how understandings and beliefs about the discipline, children, learning, and the contexts and purposes of education, shape what a teacher does. We don’t view this relationship as one in which any of the particular constructs we have just listed are held constant and unchanging. We believe that as a teacher teaches their substance alters in response to one another. Images and understandings of the discipline of science change as the needs and goals of students are negotiated. We argue that, in effect, science is re-made, re-defined in provocative and important ways, by teachers as they work. We also think we do this ourselves as we teach science and science pedagogy in unconventional ways.

We seek to develop an understanding with the students of the nature of the science from multiple perspectives. This is based on the conviction that science as an activity is complex—it is not a simple matter of mindless application of ‘scientific method’. Science occurs in a context; people do science for purposes. The form 'doing' science takes is shaped from an understanding of purpose; doing science is a social event in which people interact and bring their own areas of expertise. All of this has special and diverse meanings for scientists, and also special, and possibly different, meanings for teachers and children.

To develop such an understanding of the processes of science, we are purposefully blurring the edges between aesthetics and science. Such a blurring redefines the nature of what it means to do science or art in provocative ways. We began this paper by asserting the similarities and differences between science and art. Engaging in the two in ways that invite examination infuses both with a wonder and beauty. By blurring the edges between aesthetics and science, a sense of playful enchantment arises. This is apparent in each story.

Re-enchantment and wonder are two of the central components of the science we wish to enact. The purposes of developing such a science and science education include an attempt to enlarge the creative spaces available to others and to validate the creative acts that surround us. Such a theory portrays neither art nor science as monolithic or stationary. Both become what teachers and students make them. Reciprocally, such experiences change the teacher and the students. We would argue that rather than increased test scores or vague concepts, such as 'scientific literacy', the outcomes of education should be more ambitious. Education, science and art are processes justified by the satisfaction they bring the practitioner. How that satisfaction is defined is at issue here. Is it the satisfaction of a credential, of a test passed, or something deeper and larger? As we merge science and art in our classrooms, our students develop a sense of the dialectic between rationality and the aesthetic, between emotional responses and intellect. They recognize that each enriches the other.

In many senses, teachers build and inhabit a playful, magical terrain with each other—a fantasy land—as they engage in the activities we describe. We recognize this terrain as socially created in many dimensions: it is created through the communities of the classroom and elsewhere, and it doesn't exist in such a rich form outside the social setting. The teachers construct meaning as a dialectic with the activities, and in a dialogue with each other, and they share between themselves and, in an expanding sense, with others, including the children in their individual classrooms. We do this also, constructing meanings and values as a dialectic between what we are experiencing, our histories, our subjectivities, and our purposes. Such intellectual playfulness enables our creativity, our thinking outside of preconceived definitions of subject matter. It underlies the understandings we construct. In merging art with science through play we enhance this process, enriching it in content but also in something felt, something emotional, which is developed through the activities and also through interactions with others. Again, this is a component of re-enchanted science.

For us, as teachers, we realize that such a re-visioning of science as playful fundamentally involves a radical political dimension. Our sense of commitment and passion in our work is an ultimate recognition of our own subjectivity. This is an expression of how our ways of knowing are rooted in community, in our classes and elsewhere, and that these in turn reflect our subjective positions. We would argue that, instead of increased test scores, science education should concern itself with the transformation of both teachers' and learners' roles, and that this entails a transformation of subject matter.

Notes

1. When Dewey (1933) dichotomizes ways of knowing into 'knowing of' and 'knowing how', he is speaking first of knowing things about a subject matter (for instance, he doesn't limit his argument to formal subject matter). So, having knowledge of, e.g. electricity, is having facts and theories about how it works. 'Knowing how' is about how a person uses knowledge, e.g. knowing how to make an electrical circuit to wire a house. Neither the first nor the second necessitates or requires the other.
2. The argument and the dichotomization of education into utilitarian and liberal extends throughout the conceptualization of education in the US. It is deeply rooted in Dewey's pragmatics and epitomized by the argument over vocational education in the early part of the 20th century. Dewey's original conception—again echoed by the US social reformer Jane Addams when writing about education for the immigrant—was that through application in the practical, the intellectual could be given new meaning and form. And, conversely, the values and goals inherent in an articulation of a practical problem would be re-examined through the development of intellectual tools. Dewey's argument was that both vocational and liberal sides of schooling were complementary and rooted in the same (democratic) foundations. The argument has become much more complex since the reforms of the 1950s. Since that time, for example in science education, conceptions of what is valuable to know in science have shifted back and forth between the two.
3. For example, see Eisner (1998).
4. See Osborne and Brady (2000, 2001) and Osborne and Barton (2001).
5. The CAVE is a projection-based virtual reality system at the National Center for Supercomputing Applications at the University of Illinois at Urbana–Champaign. Projection-based virtual reality displays, such as the CAVE, display 3D images on video-projection screens or monitors; users wear lightweight stereo glasses to view them. Such an environment effectively immerses the viewer in the three-dimensional scene, allowing them to move through it in a realistic manner.
6. The purpose of the Argus project is to create a computer network that can acquire and integrate data from a large number of cameras located at different viewpoints surrounding one central object. The data from the cameras is used to compute a three-dimensional reconstruction of the object. The utility of such real-time three-dimensional data-acquisition and -processing will be tested by relaying the three-dimensional data to the CAVE virtual reality environment. This relay would allow a CAVE user to view a three-dimensional reconstruction of a scene at a remote location, with the ability to view from all angles and positions.
7. We borrow the word 're-enchanted' from Berman (1981), Gablik (1991), and Levin (1988). To quote from Gablik (1991):

> Re-enchantment as I understand it, means stepping beyond the modern traditions of mechanism, materialism, secularism, and scientism—the whole objectifying consciousness of the Enlightenment—in a way that allows for the return of soul. Re-enchantment implies a release from the affliction of nihilism, which David Michael Levin has called 'our culture's cancer of the spirit'. It also refers to that change in the general social mood toward a new pragmatic idealism and a more integrated value system that brings head and heart together in an ethic of care, as part of the healing of the world (p.11).

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