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A Different Understanding: Science Through the Eyes of Visual Thinkers

S.C. Sesko
M. Marchant

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A Different Understanding: Science through the Eyes of Visual Thinkers

Stephen C. Sesko, Ph.D.
Education Program, Lawrence Livermore National Laboratory
Melanie Marchant, Ph.D.
Cosumnes River College, Folsom Lake Center

Abstract

The objective of this emergent study was to follow the cognitive and creative processes demonstrated by five art student participants as they integrated a developing knowledge of "big" science, as practiced at the Department of Energy's Lawrence Livermore National Laboratory, into a personal and idiosyncratic visual, graphical, or multimedia product. The non-scientist participants involved in this process attended design classes sponsored by the Laboratory at the Art Center College of Design in California. The learning experience itself, and how the students arrived at their product, were the focus of the class and the research. The study was emergent in that we found no applicable literature on the use of art to portray a cognitive understanding of science. This lack of literature led us to the foundational literature on creativity and to the corpus of literature on public understanding of science. We believe that this study contributes to the literature on science education, art education, cognitive change, and public understanding of science.

Background

In 1995, the Lawrence Livermore National Laboratory (LLNL) -- a multidisciplinary research and development center operated by the University of California for the U. S. Department of Energy -- contracted the Art Center College of Design (ACCD) in Pasadena, California, to develop a new "corporate image" for the Laboratory. The Art Center is an academic center for designers and visual arts professionals. This is a typical assignment for their students.

The original ACCD course, entitled "Creating an Identity for a National Laboratory," emphasized the design of a logo (Figure 1), ID Badges (Figure 2), letterhead, name cards, and other traditional corporate artifacts.

Figure 1. Logo

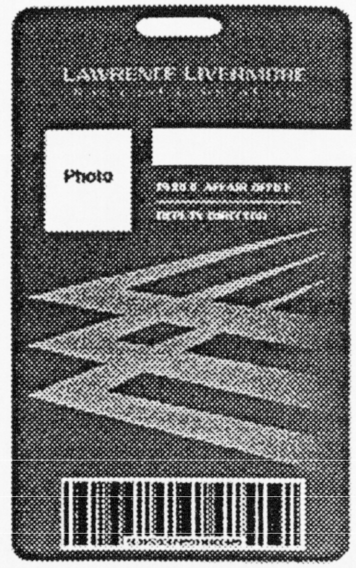

Figure 2. ID Badge

In this class, the approach was four weeks of research into the client and ten weeks of product development. At course end, each student would have created a "book" that was his or her visual, graphical, and often textual conception of how the new corporate image would appear.

By the spring of 1996, not only had the title of the class changed to "Creating a Visual Synergy for Science," but so had the emphasis. Under an innovative concept developed by the professors of graphic arts and incorporated into the new course, the students were asked to do ten weeks of research and four weeks of product development.

The reasoning for this new approach to the design process is best explained by the two professors who developed the idea (italics ours):

"There has never been a more challenging and demanding time for graphic design. Today students must not only be proficient in the traditional areas of typography, layout, materials, and color, but new technology, as well. They must embrace interactive media with critical thinking and exploration.

".... We seek those who *will look beyond the surface and make a complex idea clear.* ....They will need an understanding of cognitive science, science, history, politics, and theater to prevail. *Effective design comes from knowledgeable designers.* (Miho & Thomas, 1996).

The students in the new class were asked to use the knowledge they had gained of the Laboratory's scientific programs, not as the basis for a corporate product, but, rather as the basis for a visual, graphical, or multimedia product that depicted their personal and idiosyncratic understanding of the nature of science at the Laboratory. The project thus became a lesson in the development of scientific literacy, about "big ideas," and about their expression in an artistic product.

As artists, these students had <u>chosen</u> to have a limited academic background in science – not much beyond what was required of them in school. During the 14 week course, the students did extensive research on the kind of "big" science that is conducted at LLNL. They came to our Laboratory and toured various departments; they spoke with LLNL scientists. They were also asked to be more reflective about their own thought processes as they developed their products. We explained that it was their thinking about the product that was important to us.

The objective of this study was to follow the cognitive and creative processes demonstrated by the student research participants as they were integrating their developing knowledge of "big" science into this product. We believe this study offers a unique perspective on science education, art education, cognitive change, and creativity. We also believe that this study offers a different perspective on public understanding of science.

Literature

We found no specific studies in the science education literature that addressed the understanding of science through a medium other than traditional school-based science courses. The literature in the field of art as a transfer medium was similarly weak. For this reason, we turned to the corpora on art education, creativity, and scientific literacy. This literature provided us with broad conceptual themes rather than qualitative or quantitative research studies. From the science literacy literature (AAAS, 1990, 1993; NCEE, 1995; Newman, Griffin, and Cole, 1984; NRC, 1994; NSF, 1990, 1991) and from the literature on creativity (Hardison, 1989; Koestler, 1964; Loewen, 1995; Stoppard 1994), we developed the following synthesis.

Modern science, whether in the classroom or in the laboratory, is arguably based on two key assumptions: 1) there is an underlying order to the seeming disorder in our world; 2) events in nature have causes which can be identified and understood. New approaches to science education encourage all learners to view and understand science as an open-ended exploration of the experiences that happen in the world, rather than as a closed body of knowledge to be memorized and repeated by rote. Creativity studies support these ideas but are, surprisingly, not referred to in the science literacy literature.

The above assumptions, similar to thinking in the creativity field, also imply that science is a collective -- a social -- practice, with individuals across cultures and time, sharing observations, hunches and insights, as well as successes and failures. The understanding of our world is such an immense undertaking that it would be mistaken to assume that science could be practiced any other way.

This vision of science as an effort in which anyone can engage -- even a small child who may observe simple harmonic motion in a slinky -- means that we all ask a lot of questions and make many observations; that we debate, but that we remain open to all possibilities; that we remain skeptical, to minimize the risk of being misled or fooled. Perhaps it simply means that all adults and children rediscover, or retain, the wonder of the science of our youth, an idea argued in Papert (1984) and Kozol (1980).

In content, the new thinking emphasizes the "big ideas" of science, systematic questioning, and investigation. Such activities stress experimentation skills rather than instructions from a book. Such activities encourage concentration on the major themes and examination of these themes in greater depth, rather than concentrating on lower level thinking skills.

The concepts expressed in these new visions of science literacy and science teaching and learning are the basis of the research environment in which the Art Center students worked. It was this environment and the products of this environment that we studied. In our data analysis, we focused on the following themes from these collections of literature:

1) to look beyond the surface and make a complex idea clear;
2) to look for an underlying order to the seeming disorder in our world;
3) to view science as a collective -- a social -- practice with individuals across cultures and time, sharing observations;
4) to view science as an effort in which anyone can engage, often with a child-like approach;
5) to view the "big ideas";
6) to concentrate on major themes and examine them in depth.

We also focused on some of the criteria proposed by their faculty, namely:

1) to think critically and explore;
2) to look beyond the surface and make a complex idea clear;
3) to create individual statements;
4) to understand science and history.

Methodology

The class involved first, a tour of various scientific departments at the Livermore facility. As the class progressed, the students had access to numerous articles, brochures, reports, and other materials published by and for the Laboratory. They also did their own research about the Laboratory through newspapers, news magazines, the World Wide Web, and other sources of their own choosing.

Process and data collection

Our participants were asked to answer short questionnaires about their experiences with, and attitudes about, science before and after taking this class. These answers became data for comparison with the thematic literature. We asked the students to record their cognitive and intuitive creative processes in both journals and sketch books. These artifacts were also later used for analysis.

An understanding of the personal interactions these students had with art and science could not be addressed by either the theoretical literature or the questionnaires alone. The personal and idiosyncratic nature of these issues indicated that this information could best be gathered through an interview process. We conducted 60 minute face-to-face interviews, using techniques found to be effective by Fine and Sandstrom (1988), McCracken (1988), Seidman (1991), and Yin (1989). The question development techniques were derived from, but were not exclusive to, ethnographic interviewing, as discussed by Spindler (1988) and Wilcox (1988). The interview questions were open-ended, such that patterns of thinking, and many other concepts, would emerge from the answers. In addition to open-ended questions, our techniques included the judicious use of probes, and the use of extensive follow-up questions.

The data were highly reflective and personal. I. E. Seidman (1991) calls this process, "the ability of people to symbolize their experience through language."

We also developed questionnaires based on the materials produced by the subjects in the process of creating a depiction for LLNL. These materials included both written and artistically rendered notes used by the students in the development of their depiction, including their ideas about science and about the Laboratory.

The final "Visual Synergy of Science" products, their "book," were presented on the last day of class. These were collected, analyzed, and used to support themes that had emerged in both the literature and in our qualitative research. Our methodology was to analyze these journals and sketch books to determine themes that are alike, similar, and divergent from one and other.

Data analysis

The theoretical framework was also exploratory. The research participants elucidated the issues in the study from their own observations, using their own words, drawings, and "marks." We conducted the research from a phenomenological perspective: what the structure and essence of the science/art experience phenomena were for these participants.

We used the narrative data in conjunction with the textual material to determine if there was a grounded theory that could be developed to begin to explain the process of how non-scientists, particularly artists, come to an understanding of science.

The development of codes and themes resulted from particular suggestions found in McCracken (1988) and Seidman (1991), used within a design defined and described by Yin (1989). In this study, each participant became, in effect, a separate case study -- each participant vignette is a literal replication of the study. When compared and contrasted, the cross-participant codes and themes become a multi-case study that also yields the possibility of replication. Codes were used to determine themes, which were considered provisional until quite late in the process. The importance of the theme was relative as well. While some areas seemed of great importance to one of us, these same themes may have been unimportant to the other.

Unlike studies done in laboratory situations with specific measures to analyze the results of specific variables, this study investigated the participants in informal situations, with no specific variables. There were no preconceptions of what results would be found. Newman, Griffin, & Cole (1984) argue that, in informal situations where the data are emergent, it is not possible to control for specific variables; nor is it possible to predict the kinds of data that might be obtained. Without specific variables, it is not possible to develop formal measures of data that can apply to the material obtained. The data for this study were the ideas, opinions, and revelations of the participants. They are measured by comparison and contrast, not by specific tests.

Data presentation

The data produced a rich, descriptive narrative that identified modes of thought and interactions the artists had with science. Stories, narratives, and anecdotes have always been a way of creating meaning; they are one way of knowing. The research participants explained their experiences with art and science in the stories they told during their interviews. The students selected details of their experiences, reflected upon them, made personal sense of them, then narrated them to us. Taken together with the written and artistic data, the stories coalesced into our understanding of the students' experiences. We attempted to discover what was both consistent and different among these stories. This analysis became our understanding of how these participants think about and express science through their art.

The individual student data were written up as vignettes of each student's experience in the student's own words. The elements that emerged from the work with the questionnaires, the interviews, the artist sketch books, the journals, and the final project materials comprise the presentation of the data.

Participants

The sample selected for this study is what Patton (1990) would call "typical case" sampling (p. 173). This kind of sample can be taken from survey or similar data. Its purpose is to provide a "qualitative profile of one or more typical cases to describe what is typical...not to make generalized statements.... The sample is illustrative, not definitive." (p. 173)

The five participants in this study were self-selected from four classes that took place over a period of nearly two years.

The five volunteer participants were all Caucasian males in their early twenties: one was 23; one was 25; three were 24. The youngest was a senior student, the other four were juniors. Four were majoring in Graphics/Packaging, one majored in Communication Design.

Data

Participant attitudes toward science before the ACCD class

We looked first at the experiences and attitudes the students had about science before they participated in the ACCD course. These data come from both the interviews and the questionnaires.

Student Number One is from Europe.

"As far as I remember, my first contact with the subject of science was in my first year in elementary, it was called 'Sachkunde,' in English it means more or less - how things work. The main purpose of the class was to make kids interested in science. In my years at high school, I had to take courses like chemistry, physics, math, but with a special focus on engineering. (It is a high school specialized in educating the students for the engineering branch in industry.) Unlike other high schools in Germany we had additional courses in 'Structure Physics,' 'Electricity,' 'Electronics,' 'Digital Processing,' and a few others I can't recall.

"I think at the beginning of my school 'career' I had more enthusiasm regarding scientific topics, during my time on high school I lost this enthusiasm because it was getting too much of a 'work-thing' in other words you had to learn formulas and numbers by heart, which is not my way of working, I preferred to be satisfied with the fact of knowing how something works, or what effect it has on my life (not numbers, or formulas). In my first years in elementary I learned the pure basics of science. In the following years in high school everything was more refined, which was also quite interesting, because I learned always something new, but the final exam was more than a pain, because you were just asked to apply formulas to mathematical problems. This fact also underlines my 'average' in school, because personally I think I have a very good understanding of science in general."

Student Number Two is also from Europe.

"In high school I took two chemistry classes, six math classes, five biology classes and about three physics classes. Three of the biology classes were considered more important, since it was one subject that I had as a graduation class. That means that we had this class about 8 hours a week. (for the last two years of school) When I say three physics classes that means that I took the class for three years.

"I was an average student in all science classes except biology, where I was pretty good. I was very interested and had no problems memorizing scientific terms or understanding certain systems of how things work in a cell for example. For the other science classes I think I just was not interested enough to be a real good student.

"I thought of science as being very complex, and very specialized. In some ways it was a little scary, too. There was definitely a sort of fascination about finding out how things work. I guess biology was my favorite because it is the closest to 'real life.' My interest in science did not expand to the outside of school though. My thinking about science was limited to what we did in school. I did not spent any of my spare time dealing with science.

"Tchernobyl happened when I was still in high school and we lived near the Rhein where once in a while there would be some kind of chemical spill that kills a lot of life in it. So generally my attitude was skeptic. Most of my science teachers were pretty boring people. I think that had a great impact on not liking physics and math."

<u>Student Number Three is from the United States</u>.

"I had a life science in junior high school and a biology class in high school, and I had like chemistry and physics, combined, maybe it was a semester each. I've had a bad attitude about it. I've never really liked it. All of them. I never really felt a close connection with any of my teachers. I don't know if it was that or the fact that I wasn't interested in it. It was just confusing, all those formulas and equations, and I just wasn't interested. I didn't like it. I didn't see the connection it had with anything I was interested in.

"I'd say that I was average (in science.) I know that in my last semester of chemistry I got a "D" and my teacher said I know that you're going to go to college and study chemistry. He knew it just wasn't my thing, but I didn't. I know I could have done it, I just chose not to. . . . I never made that connection in high school, I just didn't care. I mean, I couldn't make that till now and I never thought about things like that in high school."

<u>Student Number Four is also from the United States</u>.

"Well, the basics: biology, intro to astronomy, health, summer school at the museum of science and industry. Disinterested. ....good student; always asking why do it that way. .....interested in observing, learning; I did not have a preconceived opinion, which might have had a bias effect on my views. ......it is interesting to watch and wonder why things are the way they are. I've noted that the majority of people are not interested in knowing why this works like this."

<u>Student Number Five is from the United States</u>.

"Junior high had a Earth Science, another sort of science, which was more chemically side, chemistry, things like that. Did that Bunsen burner thing, and things with the rock, porous and the hardness, and, high school had biology class and plants. And I remember seeing a video, the whole sex thing, reproduction, osmosis. Back to junior high, the first science class was about clouds and precipitation. High school there was life science. I don't remember the chemical side in high school. I don't remember there being that much. Junior college there was physics, velocity, periodic table and motion, speed, work, force. Light, Lasers."

(Tell me what kind of science student you were. Just a general description. Good/average/poor, interested, disinterested, bored, curious, not curious.)

"To be honest, all of them. It depended on the day and the subject.

"I would say interested in wave form, highs and lows in mid range, nothing extreme.

"It seemed very different from everything else. It seemed like a completely different world. I remember in these physics classes where you'd actually do the experiment, that was the fun part, and maybe you'd record it or write something about it and ... or seeing ... you know, you'd do the experiment and go out and you'd kind of manipulate it to make your own little something. There is instant result. You do it and there's your result. The math is just .... I did like math, figuring out puzzles and stuff. But it just seemed so repetitive, the same thing.

"In the beginning, yes, being projected as having something to do with science, and then you get this feeling or this notion of what science is supposed to be and then when we went up north, then I extracted something and my view changed because now I was interested."

The data indicate a known fact: the two European students took far more science in school than did the Americans. All believed themselves to be good or average students in science. Three of them enjoyed science, because it appealed to a need in them to "find out how things worked." The American students were uniform in their dislike of the mathematics component of science, even the one who indicated that he was good in mathematics. The prevailing attitude of the Americans, supported by one of the Europeans, was that science seemed to have no connection to their everyday lives. It was, as student number five put it, "a completely different world." We noticed that, despite their lack of interest in "school science," the students had a good grounding in the basics. We also noticed that despite their lack of interest in "school science," the students were not totally disinterested in science in general. They were interested in nature, in how things work, and in hands-on exploration and investigation.

Participant attitudes toward science after the ACCD class

We were then interested in whether the class had effected any change in the attitudes they had previously held.

Student Number One

"Yes, I think I was more open to the subject, as I would have been when just had finished high school, because back then I had had enough of science.

"It was just refreshed. I think I learned to conceptualize better. Teamwork, working together with (Student Number One). Working in a different way, unlike other projects I did until now."

Student Number Two

"I do not think that my overall attitude changed. It might have become clearer. I still think that science is very useful and cannot be stopped even if we wanted to. I t has it's very dangerous sides that have to be dealt with in a different way then it has been done in the past. I think the people have to understand science better in order to gain more control.

"I learned the fine distinction between technology and science, which was not as clear to me when I started the class. I looked at a lot of writing on science and ethical\moral issues. Articles on how science effects our thinking and perception of the world."

Student Number Three

"Yes, I think my attitude changed. Yes, I think what I did was I found a portion of science I was interested in. Kind of the more spiritual, mystic, like Jung and Mandalas and Buckminster Fuller who people thought he was a little strange I kind of found that part of science that I like and branched off to that. I'm sure there would be people who would say that this isn't science because it's not as solid as equations and lasers and labs, it's a little bit more what I like. But it made me realize that there is a connection between it, although I don't think I would go take a chemistry class now, although I'd probably appreciate it and I'd find something to apply to art, but it's not I don't think I'm not that interested in it, but I realize that the connection is there.

"I think I learned that science is a lot more like art than I thought. When it's taught, it seems like it's taught like this is how it is, only these equations. It seems like a lot of the things the Lab discovered are discovered by chance. I don't have any examples, but how they're studying something else, all of a sudden they come up with something else, like that thing that beeps when the car backs up or they randomly discover. It's exactly pretty much the same way I came up with the book. It's not really all formula."

Student Number Four

".....NO I've concluded that people need to reawaken to the fact that we are part of systems, we are part of families, communities, ecosystems and that's a fundamental identity for us. Americans are obsessed with personality and individualism and if we don't reawaken to this fact we basically don't survive.

".....My attitudes toward science have not change much, the only thing that has dawned on me, since learning about LLNL, is we have technology that could forward my ideas into reality.

"......About the way things work in science, not much. But in a certain sense I have learned much about the way things work regarding peoples attitudes towards the betterment of man. I've learned that progress is not as good as it sounds. P.S. those liquid smoke crystal things were pretty neat."

Student Number Five

"I guess my cousin is a biochemist and he did an article in a local magazine and he had an example of some diagram and it was just that language, or an example of like how powers go, and with a two, and his seemed to be about 10 inches long, so, uh, coming back, it made me see more deeper into what science is. Like there's a lot more depth, and just being more aware."

Following the class, three students -- the two Europeans and one American -- who had had positive ideas about science when they entered the class, found those ideas "refreshed," "become clearer," and reinforced. The other two American students changed their attitudes: "I found a portion of science I was interested in;" and "it made me see more deeper into what science is." Two students discovered a deeper meaning in the difference between science and technology, and one student was able to see a strong connection between art and science. We noticed several themes in the interviews:

- an interest in and a fascination with technology,
- a sense of spirituality, as opposed to religiosity,
- a strong sense of ethics,
- a reflection of the altruism indicated in their background characteristics,
- an idiosyncratic view of science,
- indications that they viewed science in a way similar to the way they viewed art.

Participant final products

When we began the analysis of the students' final projects, we reviewed the themes that we had developed from the general literature and from the manifesto created by the two professors at ACCD (page 4). We decided to concentrate on the following themes:

- to look beyond the surface and make a complex idea clear,
- to look for an underlying order to the seeming disorder in our world,
- to view and understand science as an open-ended exploration,
- to view science as a collective -- a social --practice with individuals across cultures and time sharing observations,
- to view science as an effort in which anyone can engage,
- to view the "big ideas,"
- to concentrate on major themes and examine them in depth.

We were also interested to see if any of the themes we had noticed in the interviews would be reflected in the art projects.

Students One and Two

The two European students worked on the final project together: Student One for the original graphics, Student Two, the text. Both were involved in the selection of the photographic art. The product as a whole demonstrates their use of design as a medium to express their idiosyncratic understanding of science. The technological background of Student One and the newly acquired understanding of technology of Student Two are clear.

An important aspect of the work is their reflections on the ethical needs of man in relationship to science. We saw several of our research themes carried through into the project, e.g., technology, ethics, altruism, the similarity of science and art. The texts for the product come from such varied sources as Lewis Wolpert, Wired Magazine, Oppenheimer, Hegel, and Asimov. Accompanying the book was an interactive CD-ROM disk that delved into the nature of technology.

The book is entitled "planet livermore one." It is intended to be the first issue of a publication from the "Ethical Consultant Department" at LLNL, because the students see a need for strong ethics in the practice of science. They believe that a national laboratory should, and could, take the lead in establishing such an office. The book is their representation of their expressed altruism.

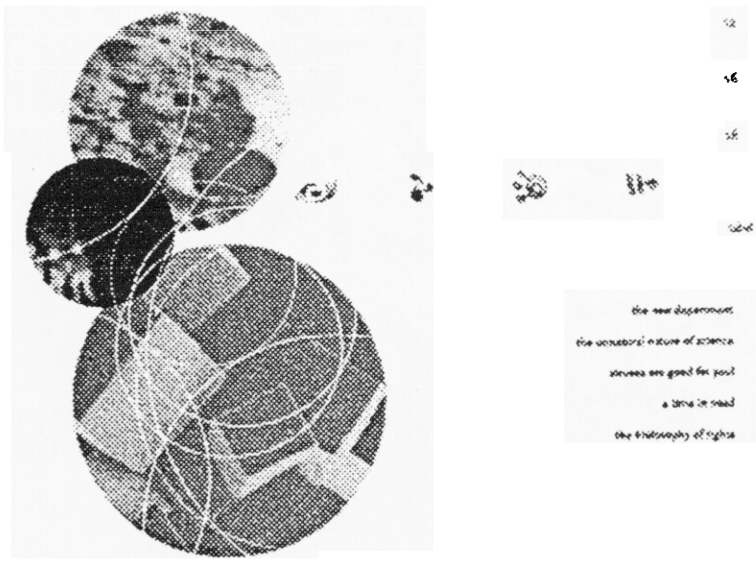

Figure 3. Contents page of the book.

The Contents page (Figure 3) shows some of the numerous small technology-inspired drawings of Student One. The contents point to a description of the new "Ethical Consultant Department," an article on the "unnatural nature of science," one on computer viruses, and others. Notice the use of "worlds" in the graphic, showing the universality of science.

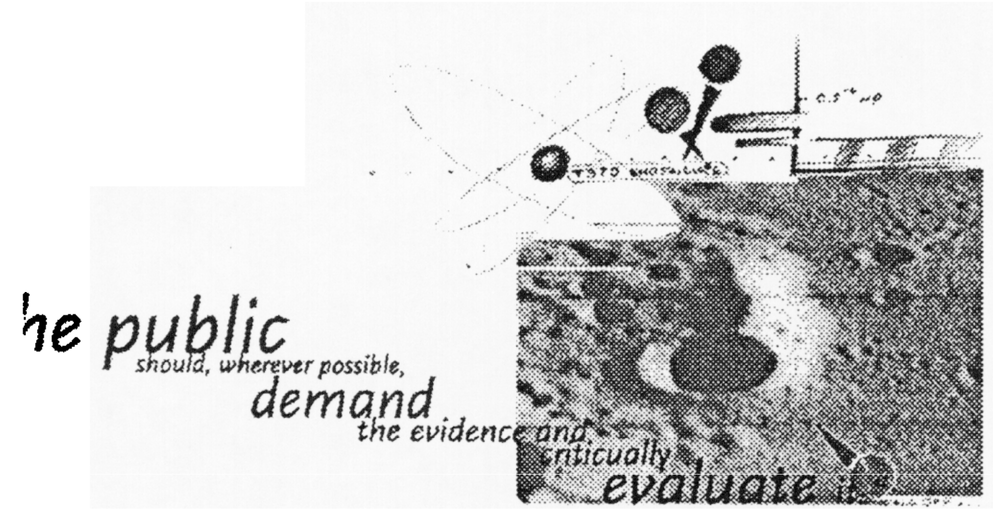

Figure 4. Quotation from Oppenheimer.

Figure 4 presents a quotation from Robert Oppenheimer: "And the public should, whenever possible, demand the evidence and critically evaluate it." The quote is taken from a longer piece by Oppenheimer that accompanies this graphic. The graphic of the surface of the moon carries forward a vision of the future and the universality expressed on the Contents page.

Figure 5. A signpost for humanity.

We called the graphic in Figure 5 "A signpost for humanity," because it shows the concern that the students have for others, superimposed over a picture of chromosome banding, a major idea in the biological sciences. The sign post itself is the shape of a "YIELD" sign. Yield to humanity. The students have attempted to combine science with philosophy and ethics.

Accompanying this graphic is a short text from Asimov which summarizes the thoughts and the philosophy that the students put into this product:

> "A public that does not understand how science works can, all too easily fall prey to those ignoramuses... who make fun of what they do not understand, or to the sloganeers, who proclaim scientists to be the mercenary warriors of today, and the tools of the military. The difference... between... understanding and not understanding... is also the difference between respect and admiration on the one side, and hate and fear on the other."

The students are interested in "raising moral and ethical questions," not in giving pre-planned answers. This new Laboratory Department is conceived as a forum for thinking and discussion. The publication, "planet livermore one," welcomes diversity by inviting guest contributors -- scientists, writers, and philosophers.

We believe this work represents a deep understanding of science as an open-ended exploration and a collective practice in which anyone can engage. These young men are only two recent individuals sharing observations across cultures and time, looking for an underlying order to the seeming disorder in our world.

<u>Student Number Three</u>

This student developed a book of carefully chosen philosophical texts whose major theme is mandalas, reflecting the spirituality expressed by the student in his interview. It is a mammoth book of over 100 pages held together by a bolt, allowing the pages to "fan" out in a circular shape of the reader's choosing, i.e., the reader can show as many or as few pages as he or she wishes. The shape IS a mandala. In using the mandala as a theme for the future of the Laboratory, he also shows his connection of science and art, in a very idiosyncratic way.

Mandalas have been used ("scientifically") to predict and celebrate the movement of the moon and planets. Stonehenge, seen from above, is a mandala. The student used many examples, religious, non-sectarian, and those he created himself.

This student was interested in using the mandala as a metaphor for the Laboratory. He saw the Lab in need of harmony because it acts upon, and is, in turn, acted upon by other entities. He also saw the Lab as "a reflection of America." The student felt the mandala could offer LLNL a symbol of reunification. One of his quotations clarifies this metaphor, "In the present struggle of the planet, the mandala represents itself as the seed-symbol of a more harmonized world order." The Laboratory could be the seed-symbol of an unfolding harmony between science, education, the government, and the consumer.

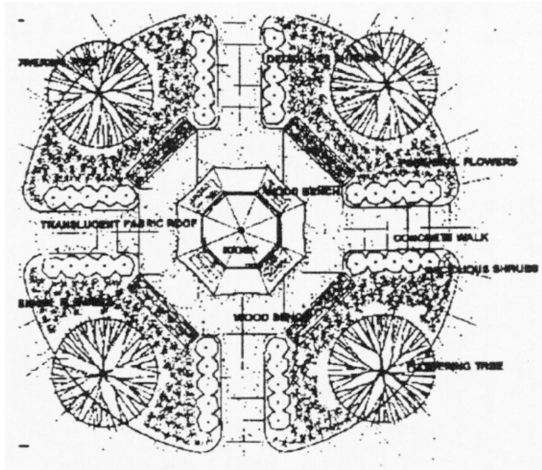

Figure 6. Landscape/architectural drawing of a Laboratory kiosk garden.

This student utilized the concept of the mandala to design for LLNL information kiosks, to be placed in spots around the Laboratory grounds (Figure 6). The kiosks were intended to display permanent and temporary information about the different departments that make up the Lab.

They were designed to be very colorful and stimulating, to encourage interaction and unity between departments and employees. The kiosks were intended to be completed with landscaping and benches to enable the employees and visitors to meet, discuss and enjoy the outdoors.

We believe that Student Number Three views science in a way similar to the way he views art. He looks for an underlying order to the seeming disorder in our world, but with a strong sense of ethics and a sense of spirituality, as opposed to religiosity. He is interested in the "big ideas," but he has an idiosyncratic view of science. Like Students One and Two, he views science as a social practice in which anyone can engage, with individuals across cultures and time, sharing observations, but he also gives a reflection of the altruism indicated in his interviews.

Student Number Four

Like Student Three, this young man carried through the themes spirituality, ethics, and altruism in his work. He, too, has a very idiosyncratic view of science, and views science in a way similar to the way he views art.

The book opens both to the left and the right, giving the reader a juxtaposition of natural and man-made artifacts. These artifacts are always of a scientific nature, whether man-made items of technology, or phenomena such as a meteor crater. Textual pages are intended to be read together in the center quadrants, with illustrations on the left and right. This design can be seen in part in the cover of the book (Figure 7).

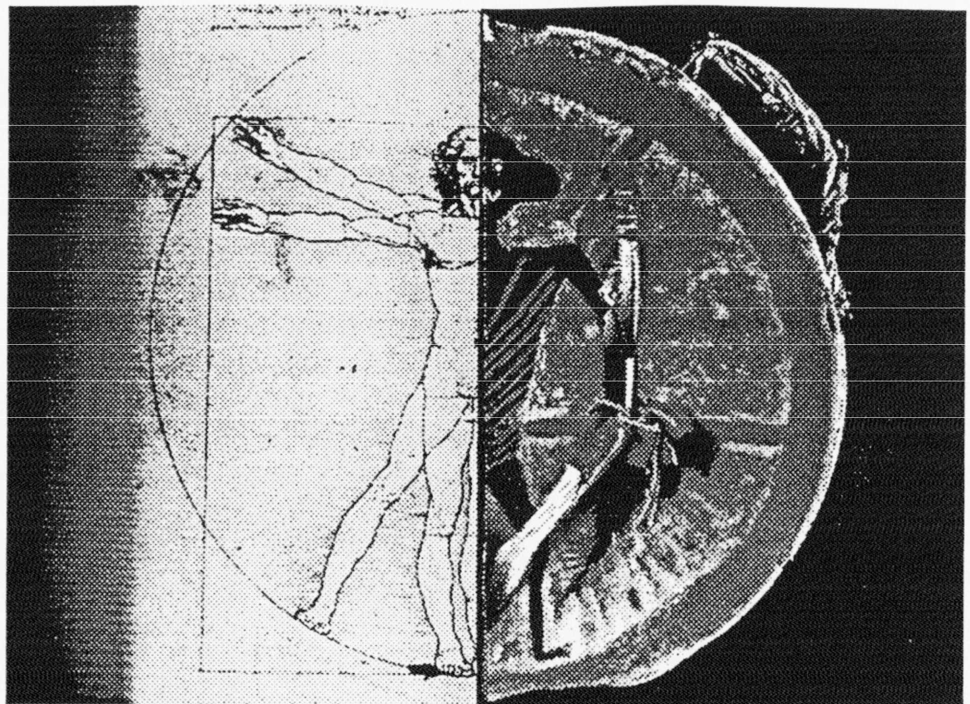
Figure 7. The cover of the book.

The left half of the cover is the da Vinci drawing of the ideal proportions of man. Man as the measure of all things. The right half of the cover is, by contrast, more primitive -- a decorated shield. Here man is seen more symbolically, and also perhaps metaphorically. Another contrast is that of the scientist da Vinci opposed and blended with a primitive concept of man, the circle of the da Vinci connecting to the edge of the shield, the two figures, right and left sides of a person.

These kinds of comparisons make up the entire book. There are comparisons between many man-made objects, natural phenomena, and many biological references. These are tied together with sparse text, allowing the graphics to do the "speaking" for the student and his philosophy.

Several of the graphics are of cathedral windows, mandalas, and other religious objects. Tied with the scientifically based graphics, the student particularly brings out the themes of spirituality and of science viewed as art.

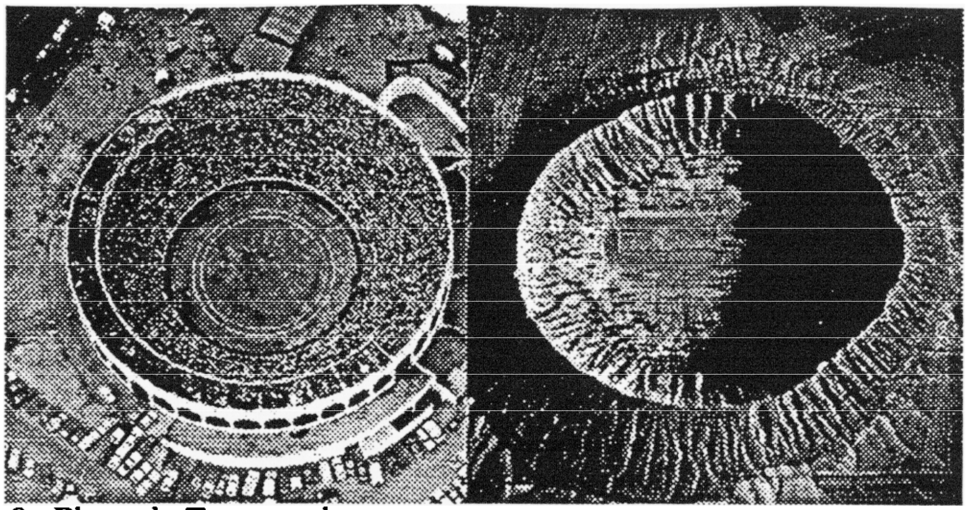

Figure 8. Plaza de Toros and a meteor crater.

The images of the bull-fight and the crater (Figure 8) are circular in shape. The circle connotes unity. This student's entire book is full of circles, from the stone wheel to the universe whirling through space. These circles are intended to be viewed two, three, or four at a time with very little text. The juxtaposition here is that of a man-made engineering artifact against a nature-made artifact. They are similar in size relative to the creator of the artifact.

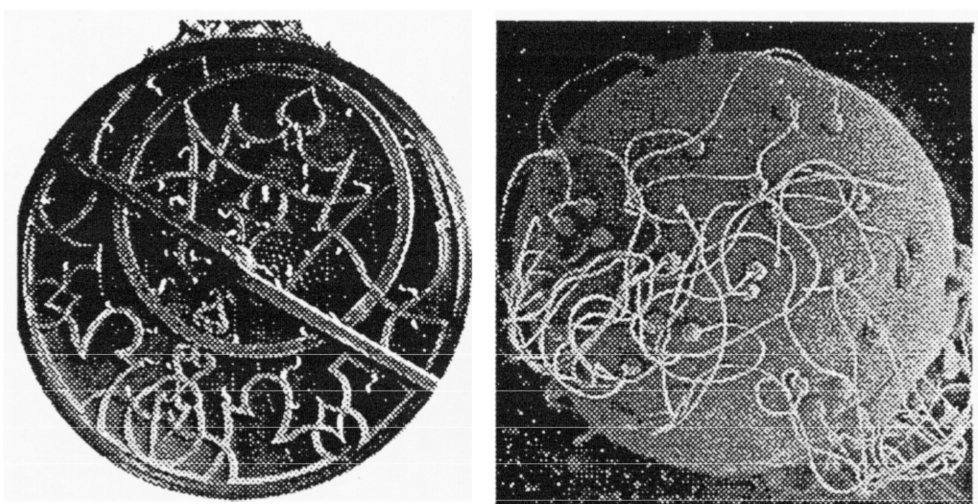

Figure 9. Astrolabe and human ovum.

This juxtaposition of the 15th century astrolabe with the human ovum besieged by sperm (Figure 9) is one of this student's astounding correlations of circles, the mechanistic with the organismic. Note the contrast between the filigree decoration on the man-made technology and the tails of the sperm as they circle and entwine the egg.

This student demonstrates a strong view science as a collective -- a social --practice. This is particularly true of the idea of individuals across cultures and time, sharing observations. He does view science as an open-ended effort in which anyone can engage, but he sees his engagement as a seeking of an underlying order to the seeming disorder in our world.

Student Number Five

This student took one small part of the Laboratory's work and developed it with great insight and sensitivity; he truly looked beyond the surface and made a complex idea clear. After the Lab tour, the students met one of our scientists who discussed among other topics, the Biomedical Program. This program is part of the nation-wide Human Genome Project. The scientist mentioned that one of the discoveries the Lab had made was the gene for dwarfism. From that one sentence spoken at the end of a long tiring day, the student developed a product that concentrated on a major theme and examined it in depth. In this work, the student showed that science is an effort in which anyone can engage -- especially an artist. Through his art observations he became part of the collective practice of science across culture and time.

The student who produced this work had deep concerns about the development of this book. He did not want to transgress from the medical aspects into a book that verged on voyeurism, so he stuck with the medical aspects very closely. He was also concerned that he would say something in the book that would be viewed as insulting to the people who have achondroplasia. He wanted to develop a book that would educate people. In so doing, he educated himself.

He completed a work of great depth and awareness. It is not technical, but it shows an understanding of achondroplasia that is beyond what the general public would have. It is an educational work. It is also done with great beauty and insight.

The cover of the book is shown in Figure 10.

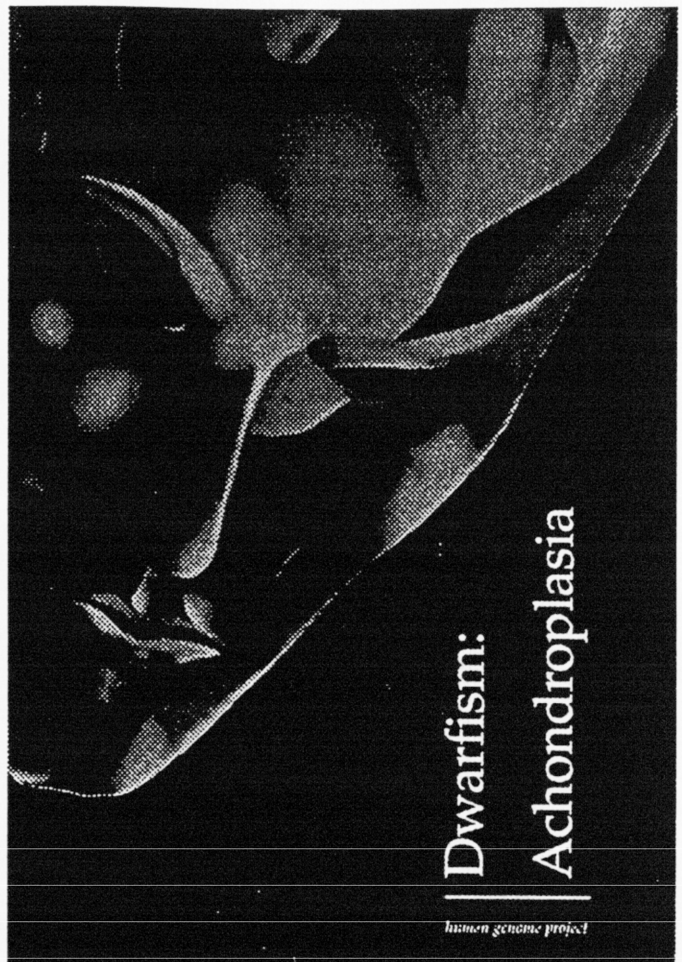

Figure 10. Cover of the book.

Our student said that he had not created this image specifically for his book on achondroplasia. He utilized an existing painting that he had done to explore another subject. This mask-like face has a fetus in the place the brain would be. The painting was used because it spoke eloquently to the inheritance factor of dwarfism. The colors and the aspect of the face seem to indicate immediately that this is not a traditional approach to the subject. It leads the reader directly into a serious frame of mind. This seriousness is also reflected in the choice of font.

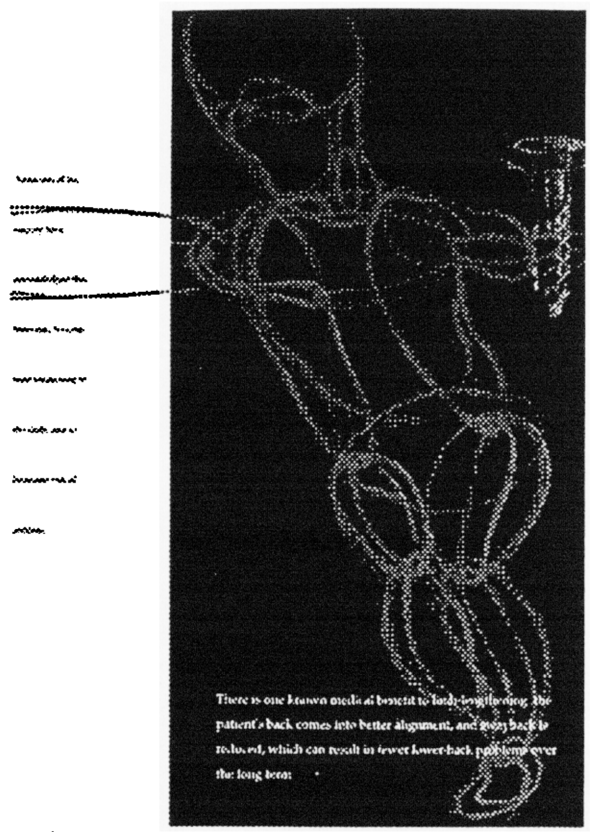

Figure 11. Limb lengthening.

This drawing accompanies a page entitled "Limb Lengthening" and explains the process, which involves cutting arm and leg bones, inserting pins and moving the bones apart. New bone tissue then fills in the gap, increasing length. The mechanical screw placed inside the arm of the person with achondroplasia effectively illustrates the process.

The few graphics we have shown from this work demonstrate that the student has a strong sense of ethics and altruism. In viewing science in a way similar to the way he views art, he gives us his own very idiosyncratic view of both.

Discussion

The participants in our study had either a very basic or a limited scientific background. For the most part they seemed to have an innate interest in things scientific at an early age, but had become disinterested in "school" science, and had self-selected out of this profession at about the high school years. The ACCD class, while not providing a strong academic background in science, nevertheless had kindled, or refreshed, an interest in science that was unique and personal to each student. This understanding is clear, both in content and personal expression. Despite the lack of science as a core interest, the students were able to depict, in an artistic form, the "big" science being conducted at the Lawrence Livermore National Laboratory. In addition, they were able to show graphically many of the major themes discussed in the literature. These themes can be seen throughout the final class products.

The ability to look beyond the surface and make a complex idea clear is especially apparent in the achondroplasia book. The insight to see an underlying order to the seeming disorder in our world can be seen in the work of Students One, Two, Three, and Four, particularly the drawing together of ethical and spiritual ideas with science.

The theme of science as a collective – a social – practice with individuals across cultures and time, sharing observations is especially strong in the work by Student Four, where he shows human science from a variety of cultures and time periods.

The theme of science as an effort in which anyone can engage is shown in all of the work. While it is certainly not in the tradition that any of the LLNL scientists would recognize, these students were actually engaged in science, often with the child-like approach mentioned in the literature.

Students Three and Four saw the "big ideas" from both a cosmic-spiritual level, and from a variety of cultural levels as well. Students One and Two saw these "big ideas" as the major ethical issues involved in science.

The approach taken by Student Five in his depiction of dwarfism was certainly a concentration on major themes and an examinination of them in depth.

The most interesting idea to us was that none of these students worked consciously to bring these themes into their artistic products. The results of these students' work is almost a meme[1].

We also learned that these students were able to fulfill some of the criteria proposed by their faculty. Students One and Two through their ethical concerns demonstrated critical thinking and exploration. The achondroplasia work demonstrated both critical thinking and the ability to look beyond the surface and make a complex idea clear. Student Four clearly showed an understanding science and history. All of the students strongly demonstrated creative individual statements.

Again, none of this learning was a conscious effort, but the results of this new approach demonstrated that the instructors are on a track worth continuing.

This study has two clear limitations, which, can be mitigated if we are able to continue the work, or if others can replicate the study. First, we would

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[1] meme: (pron. 'meem') A contagious idea that replicates ike a virus, passed on from mind to mind. Memes function the same way genes and viruses do, propagating through communication networks and face-to-face contact between people. Derived from the word "memetics," a field of study which postulates that the meme is the basic unit of cultural evolution. Examples of memes include melodies, icons, fashion statements and phrases.

have liked to have had more participants in our study. This study would have been particularly enhanced by the addition of one or more female students. It would also have been enhanced by having students with greater ethnic diversity. Second, due to our distance from the participants, it was not possible to observe them at work or use a long interview process as would be found in a true ethnographic study.

Future researchers can correlate these modes of thought and interactions to other criteria. For example, one of the most important themes that emerged from this data is the need for science and mathematics to be taught in a more visual way to these visual learners. Effective strategies that emerge from the correlational research can inform instructional programs that can be tested in experimental research.

We believe that this study can contribute to the literature on science education, art education, cognitive change, and public understanding of science. We hope that our codes and themes will prove useful to future investigators in the development of correlational studies and experimental treatments related to this topic.

Conclusion

We believe that the addition of an artistic side to science would afford many non-science inclined students the opportunity to learn in their own way. In the arts, the development of aesthetic perception enables one to respond to the elements of an object or event and to appreciate it in greater depth. The arts can, and should, play a major role in science. Each art form is unique because of the particular avenues of perception that it develops. Increased perception sensitizes the individual to the world. As one develops a fuller awareness of the nuances of light, color, sound, movement, and composition through experiences in the arts, otherwise ordinary experiences take on an aesthetic dimension. Heightened perception provides a stimulus for imagination and creativity and has impact on all learning.

Creative expression includes originating, creating and presenting, and interpreting; focusing, channeling, and encouraging communication and originality; and providing increasing understanding of the structure and language of the arts. Creative expression helps one to know one's self and to appreciate one's own and others' uniqueness. It generates excitement, encourages creative exploration, and enhances learning. This expression can be useful in science as well.

Life is enriched as the awareness and response to beauty in all of its forms increase. To develop aesthetic values, the student studies the sensory, intellectual, emotional, and philosophic bases for understanding the arts and for making judgments about their form, content, technique and purpose. Through study and direct experience, the student develops criteria for arriving at personal judgments. As Students One and Two have pointed out in their work, these elements should, and could be important in science.

We entitled this paper "A Different Understanding: Science through the Eyes of Visual Thinkers," because both science and the arts allow learners to learn by doing and creating. The prime motivations in either a science or art program are to offer learners opportunities to enhance understanding and to allow them to develop self-discipline and self-control. Both art and science can also provide opportunities to learn various concepts by non-traditional means, and to express mastery of content through presentation.

As a result of this study, we have become particularly interested in the different processes that can be used to teach science to non-scientists so that they are able to understand and portray scientific information. For non-science majors, it is clear that there are other modes of investigation and inquiry, and there are other modes of representation of knowledge than are used in traditional science inquiry.

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Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551