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Turning STEM into STEAM

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Most Universities today recognize the importance of a comprehensive education that includes interdisciplinary study. However true interdisciplinary classroom experiences between Art and the STEM fields, turning the acronym for science technology, engineering and math into STEAM, with the A contributed by Art, are not very common. Yet there is strong motivation for such interdisciplinary study, justified by the increasing awareness of the powerful role that images play as a fundamental format for scientific communication, of how images contribute to the development, communication and popularization of science and engineering, and of how images help build scientific literacy. More subtly, a full range of visualization skills, for example learning to `see', learning how to make good and careful observations, and exploring the basis for intuitive insight, are all manifestly critical skills for creative design, invention and innovation; skills required of both engineers and artists.

The thesis of this paper proposes that there are fundamental parallels between the style and creative thought processes of Engineers and Visual Artists and that these similarities strongly suggest that teaching the foundational concepts of Art, with disciplinary rigor and engineering context, would help improve critical and creative thinking, guide and encourage innovative engineering and visual art; fostering more effective direct and conceptual communication of scientific ideas and advancements. The goal of this paper is to provide a template for a foundations class in visual skills and visual thinking that would be offered to a mixed population of beginning engineers and artists. It is primarily directed at engineering educators who, if given an outline of the visual concepts, could develop and extend the engineering connections, or who would like a starting place to develop collaborations with visual educators.

The first section of this paper provides a brief introduction to the on-going dialog of Art-Engineering cross-disciplinary work and a brief overview of some of the available resources. In the next section, we present an outline structured around foundational concepts from Art. Interdisciplinary context is provided in order to establish a sense of application and relevance that can be taken on to advanced coursework in either discipline. For each visual concept, terms are defined, student outcomes are listed and an assignment is provided for use in a project-based learning environment.

Background:

In <u>Experiences in Visual Thinking</u>, Robert McKim[1] looks at the kinds of images that provide a foundation for visual thinking, which he defines as seeing, drawing and imagining. Edward Tufte's books[2,3], provide ample evidence that an awareness of visual design and an understanding of visual concepts are critical for effective statistical and scientific communication. His historical examples and worst-case examples are particularly relevant to science and engineering. Frankel and DePace[4] have developed a guide to the effective use of graphics. They structured their book around concepts that have fundamental meaning in both science and art. The sections, titled Form and Structure, Process and Time, Compare and Contrast, for example, help define what a figure or illustration is trying to communicate. The case studies offer the comparison of before and after attempts to communicate ideas. Most recently, Bill Ferster[5] explored the concepts behind interactive visualization. In this work, visual concepts are not just a final stage of presentation but hold the potential to be part of the discovery aspect of learning and research.

There have been successful classroom collaborations between Art and STEM, for example in engineering classes that require a drafting class and art classes that teach the practical aspects of perspective in drawing and the structural elements of construction. However, as engineering drawings have gone digital, many of the elementary drawing techniques have been omitted from the engineering classes and more advanced engineer concepts are seldom part of art classes. Arguably the most significant spatial visualization work in engineering has been Professor Sheryl Sorby's[6,7,8], 11-year study of the effect of developing student spatial rotation skills to beginning engineers at Michigan Technological Institute. Building on the Purdue Visualization Test[9], Dr. Sorby has not only produced a significant longitudinal study of the influence of these skills on the academic success of engineering students, but she has updated testing and course materials to include today's technology. Research on spatial visual rotational skills has clearly shown that not only are these skills teachable, but they can significantly improve student performance across a range of coursework, engineering, mathematics and science. This suggests that, in addition to providing a framework for imagination and design, additional visual skills and acuity are also likely to contribute to student educational performances.

Visualization and aesthetic skills have also been a component of an ongoing discussion regarding broadening the conceptual design of undergraduate engineering programs. This has been prompted, in part, by a population of engineering students who come to the university wanting to get more than 'just' a technical education[10]. The National Academy of Engineering offers this comment,

"*We aspire to an engineering profession that will rapidly embrace the potentialities offered by creativity, invention, and cross-disciplinary fertilization to create and accommodate new fields of endeavor, including those that require openness to interdisciplinary efforts with non engineering disciplines."*[11].

A number of pilot programs have merged art students and engineers at more advanced levels. These include, for example, the novel class in fluids offered at the University of Colorado for engineers and media art students[12] and the Arts Media and Engineering (AME) graduate education and research program at Arizona State University[13,] which allows engineers and artists to design their degree with a concentration in the other field. Many of these follow the example set by the Stanford Design Program, which offers a joint design program of Art and Engineering.

From our perspective the most significant of the examples represented by this work are those that tie visual skills to critical thinking and the process of inquiry. Our premise is that formal training in the foundational skills of visualization should be faithful to the discipline, as a foundations course for art students and broad in scope, including applications of the visual in science and engineering to provide additional context. However, we recognize that there is also a benefit to drawing parallels between visual and scientific/engineering concepts that can help students self-identify and expand their perceived roles in their own discipline.

In the next section we provide an outline of the formal visual concepts, those offered in a disciplinary art class, and provide descriptions of hands-on projects that facilitate project-based learning. Because we have identified our audience as engineering educators the emphasis is on defining the terms and concepts from art, with less description offered for the parallel engineering topics. Our suggested approach is to team teach the class; a collaboration between a professor in Art and a professor in Engineering.

Course Outline:

Engineering students are taught a particular way of thinking; most generally it can be associated with a procedure for problem solving. While undergraduates use it to solve problems that have solutions, the method is more important as a way of approaching problems that have not yet been solved. There is an emerging trend, artists are also taught a conceptual way of thinking with similar objectives. Both engineers/artists begin by identifying a problem to solve/a concept to communicate, assessing what is known/what has been done before, identifying unknowns/challenges to communicating the concept, and assembling tools that might be useful, mathematical models or experimental tests/selection of a medium or format. A significant link between students who choose engineering or art as a major is that they consistently ask what they can do with what they learn. This translates educationally, into engineers who tend to be product oriented and artists who tend to be medium oriented; it would strengthen both to move toward becoming more content oriented.

The following sequence of visual concepts is based on a studio foundations course in the department of Art at the University of South Carolina. Each concept is presented within a project-based learning environment with an associated project. The artistic medium is a digital format. The software for the student projects is PhotoShop; this venue not only builds technological skills, but is equally accessible to students and professors from either Art or Engineering. Student outcomes, in the form of visual skills are identified and definitions of fundamental vocabulary are provided. In addition, for each topic related foundational engineering/scientific concepts as well as aesthetic examples are suggested. For several of the topics samples of completed projects are provided. These are for the use of the instructors as an aid to understanding the project description. Presenting a visual illustration to students can be helpful if the possibilities for the project are expanded verbally.

The suggested class format is a combination of group discussion and individual work. Studio Art classes at the University of South Carolina meet for twice the number of semester hours. The first one-third to one-half of the class is discussion. This includes, for example, current events, scientific discoveries, university events, personal experiences, idea development, etc. This is a platform for encouraging students to identify things and ideas that they care about. During this part of the class, mini-lectures are also presented that define concepts and terms that help with using the technological platform and that set up the next project, as needed. Over the course of the several days devoted to each project, the discussion can also include parallel concepts that exist in science and engineering. The second half, or two-thirds of each class is individual work on the series of projects. The projects allow students a degree of self-discovery and internalization with respect to the concepts. At the conclusion of each project students can be encouraged to find examples that show how/where the concept is evident in existing artwork and aesthetics, or in science and engineering.

FORM: The first 5 topics emphasize form and the analytic components of visualization.

1. Shape and Scale

An understanding of shape implies recognition of visual variety. Scale helps describe interactions between shapes.

Student outcomes: Develop an understanding of the types of shapes. Objective shapes are those that are consistently defined or are obviously representational, e.g. a chair, a tree. Non-objective shapes are those that are not associated with a definitive object, e.g. random or free-form. Symbolic shapes are those that are associated with a specific concept, e.g., swastika, commercial monograms, letters or numbers.

Project 1: Construct 12 equally sized, equally spaced squares, each of which is viewed as its own compositional plane. Place one black shape in each compositional plane. Assure that there is little or no repetition in the types and appearances of the shapes. Figure 1 shows the 12-box format used for Projects 1 and 2. The 3 squares at the top of fig. 1 illustrate a non-objective shape, a symbolic shape and an objective shape, respectively.

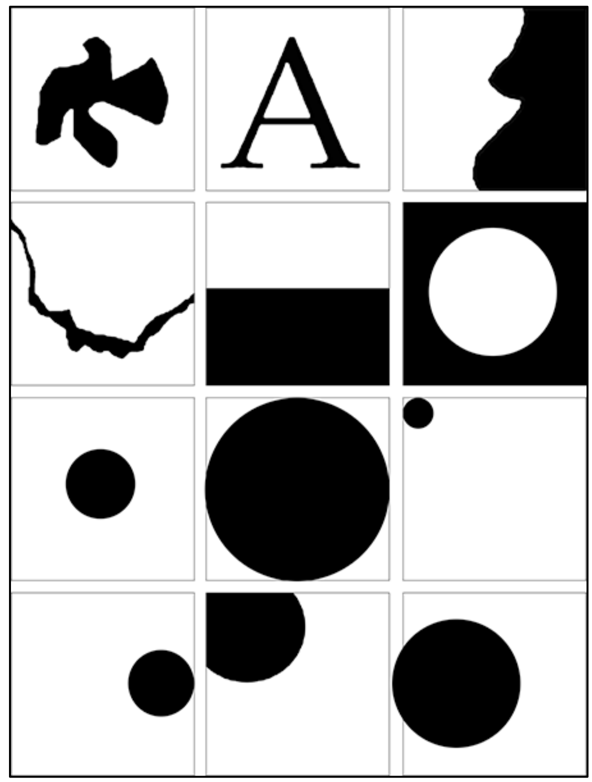

Figure 1: 12 equally sized, equally spaced squares. Format for Project 1 and 2.

Engineering Connections: How shape, or form, is connected to function; for example aerodynamic shapes that reduce drag, promote lift; shapes that have symmetry and balance; shapes designed around center of mass. Explore the challenge of increasing size, while maintaining shape/proportions. If a cylinder is made taller, its aspect ratio increases changing its flexural response. Cones or pyramids, in contrast, can be made taller, and still remain cones and pyramids. The shapes of technology include many right angles and flat surfaces; the shapes of nature include very few right angles and many more curved surfaces.[14] Shapes within shapes; pyramids made of rectangular blocks.

Aesthetic Connection: Joseph Albers' *Homage to the Square,* series.[15] Andy Warhol's *Campbell's Soup Can*[16] *(Tomato)* 1962; emphasizing an objective shape.

2. Composition and Scale

Here the emphasis is on the placement of shapes in the plane; the lower half of Figure 1 provides an example of placement in the plane and the impact of size.

Student Outcomes: Develop a vocabulary with respect to placement variety; centered, moving out of the plane, in front of or behind the plane, as well as scale in the plane. Understanding the concept that things work differently at different sizes and what the characteristic sizes are: Precious – the size of a fist or smaller; Object – the scale of non-interactive things, e.g. chairs; Human – peer or objects that can interact or confront; Public – requires distance to perceive, e.g. the faces on Mt. Rushmore

Project 2: Redo the previous problem with the same or improved new shapes but this time pay equal attention to how the shapes are placed in each compositional plane.

Engineering Connections: Boundary conditions and constraints. Discussions can be held on the importance of viscosity, surface tension, diffusion for small objects; the importance of gravity and inertia for large objects.[14] Scaling laws for linear dimension, area and volume; how these limit structures.

Aesthetic Connections: Composition: Franz Klein's black, non-objective, shapes on white background[17]. The paintings of Mark Rothko;[18] although his shapes are centrally placed, they vary in how they balance the image. *Beta Lambda*[19] by Morris Louis, in this painting the designs are confined to the corners of an otherwise white canvas. Scale: The environmental artwork of Christo and Jeanne-Claude[20] including the running fence constructed in Sonoma and Marin Counties, California

3. Multiple Shapes and Value

Here, the focus is on the relationship of shapes to one another; often this can be achieved by changes in value, lightness or darkness. Changes in value can result from contrast, patterns, transparency, and how shape edges are defined.

Student Outcomes: Develop a vocabulary of the placement and comparison between multiple shapes; separate, tangent, intersecting, overlapping; are they repeated, what is their visual weight with respect to other shapes? Are the shapes balanced in the plane? is there negative space? How do multiple shapes add visual interest?

Project 3: Establish a compositional plane that represents the largest possible working format for a single printed page (grayscale, 7.5 X 10", 150 dpi). Expanding upon the concepts of the first two problems, place seven or more shapes in an interesting compositional relationship.

Using these shapes and placements, explore the visual effects of value with continued attention to variety. These need not be individually generated shapes, as in the previous projects. A photographic image could contain the required seven shapes, but they should be consciously identified.

4. Scale

The visual concepts emphasized here are universal elements, variety, visual interest, scale.

Project 4: Establish two rectangular compositions employing multiple shapes and multiple values. One should be primarily objective, the other primarily non-objective. Select the best one, refine and print your image at a scale at least twice as tall and twice as wide as the normal printed page (15 X 20”). Crop, composite, and mount your finished product leaving a 1” boarder all the way around the image (17 X 22”).

Engineering Connections: Trigonometric (angular) relationships, symmetry, balance, equilibrium, and boundary conditions. How are intrinsic properties such as density, temperature or stiffness reflected? by shape, composition or value? How are extrinsic properties such as mass, heat, volume or momentum reflected?

Aesthetic Connection: Random patterns and the power of scale, *Autumn Rhythm* by Jackson Pollock.[21]

5. Pattern and Color

Student Outcomes: An understanding of the visual concepts of repetition, progression, and discovery; and the use of the terms hue, the color of the color, i.e., its name (12 colors, 3 primary, 3 secondary, 6 tertiary), value the lightness or darkness of the color, saturation, the intensity or purity of the color. When value changes, saturation automatically changes, but it is possible to change saturation without changing value. An ability to adhere to a systematic process.

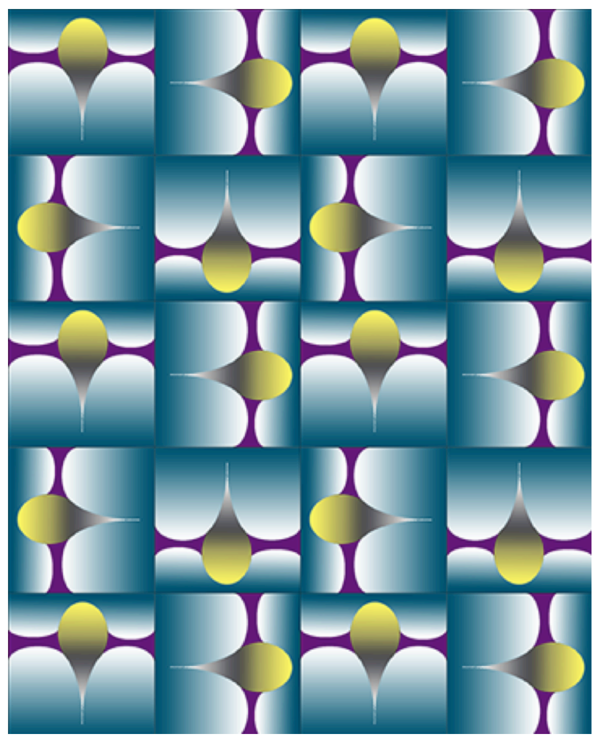

Figure 2: Image resulting from a systematic process.

Project 5: Create a design in a 3" square format, repeat the square format three more times forming a 6" square with the repeated images remaining the same or being manipulated in some logical and/or progressive way. Duplicate the 6" inch square three times to establish a 12" square, and apply the same rules to these successive squares. Finally, produce one more column and row of boxes to show a sequence of repetition, making your final image 15 X 15”. Start with a linear format, then experiment with the influence of value, and finally experiment with the addition of color. Figure 2 shows an example. The 4 squares in the upper left corner are the original image rotated in a clock sequence (90 degrees CW) and assembled. This forms the original pattern. When this pattern is assembled a second pattern is 'discovered' – second and third row, second and third column.

Engineering Connections: Color and light; polarizing filters that can be used to view value, or by training the eye when squinting, as the color receptors are at the outside of the eye. Use of color for graphical emphasis and visualization., display an understanding of the concepts of periodicity, reflectional symmetry and pattern.

Aesthetic Connection: Andy Warhol's multiple can image*, Campbell's Soup Cans*[22]*,* Graphic artists who design wallpaper and fabric.

CONTENT The next five projects focus on the concept of content in combination with form. Students start to develop more intuitive visual skills. While the first half of the projects were designed to develop eye/hand coordination and manipulative control of the mouse, the second half allows the use and manipulation of existing digital images from books, magazines, or the internet.

6. **Content vs. Form**

Thus far the focus has been on the elements of an image; here students are encouraged to be more aware of what information they want the image to convey.

Student Outcomes: Image alteration: interactions and reflections on what they know versus what they see. This can be discussed in project 3, and reiterated here.

Project 7: Scan several large head shot photos of yourself. Creatively alter one or more of these images in a way that gives the viewer insight to the true or unknown you. A good solution should be recognized as you, but also show unique and distinctive creative manipulation.

Engineering Connections: What is the graph, schematic, or photograph designed to convey, what information does it contain? How are the most important features emphasized?

Aesthetic Connections: A wide variety of historic and contemporary portraiture.

7. **Position in 3D Space**

Three-dimensional Space: Spatial illusion is indicated by 6 things, overlap (on top is closer), placement (high in the plane, relative to our line of sight, or our horizon), is further away, low is closer, scale (bigger is closer), detail (there is more detail in things that are closer), value (darker things appear closer) and color (color is richer when things are nearer).

Student Outcomes: Develop skills to convey three-dimensional space in a two-dimensional format, based on overlap, scale, placement in plane, detail and edge, value, and color;

progressive or relative construction. Develop skills in elementary drawing techniques to capture perspective.

Project 6: Scan or construct at least three visual objects that clearly identify a foreground, middle ground and a background. Employ the six indicators to generate as much of an illusion of space as possible. Consider the implied distances of space and exaggerate the spatial differences.

Engineering Connections: Building on one and two-point perspective drawing. Planes in space, the paradigms and pitfalls of optical measurement techniques. Projections of planes onto surfaces, visualization of graphs presented on three axes.

Aesthetic Connections: Chalk sidewalk drawings, for example, *Batman and Robin to the Rescue* by Justin Beever.[23]

8. **Intent vs. Perception**

Creating an image that has within it an unusual moment of discovery.

Student Outcomes: Visual research and connections; image selection and manipulation.

Project 8: Select several visually interesting images and try scanning them. Alter a single or combination of scanned images so that the final image has order and interest, and appears accurate and correct, but presents a visual reality the viewer finds disquieting and ultimately realizes is untrue.

Engineering Connections: Constructing parallels between seemingly disjoint elements. Emphasizing design, innovation and imagination. Approaches based on intuitive and counter-intuitive ideas or solutions. What can be measured and what can be inferred.

Aesthetic Connections: Liu Bolin, the Invisible Man; an artist who paints himself into the background.[24]

9. **Motion and Time (animation)**

Student Outcomes: An understanding of how form is influenced by content. Develop additional abilities in creating the illusion of space.

Project 9: Create two multi-frame, visually interesting animated movies. The first should be simple, showing mastery of the process.

The second should show the experience of several generations of creative progress.

Engineering Connections: Motion and perspective in motion. Static vs. dynamic behavior and effects. The ideas behind the concepts of continuous and discrete.

Aesthetic Connections: Early sequence of photos of a running horse, e.g. Eadweard Muybridge's *The Horse in Motion*[25], 1878. The images answered the question if all four feet of a horse were off the ground at the same time in a gallop, they are. Also of interest is Marcel DuChamp's painting *Nude Descending a Staicaser*[26], which shows all of the image sequences in one frame. Harold Edgerton[27], Professor of Electrical Engineering at MIT was one of the first scientists to use strobe lighting to freeze objects so that they could be captured on film

10. Recognition and Refinement of Visual Cues (morphing)

Student Outcomes: Develop sensitivity to small visual cues. Understand how small changes, details can have large impact.

Project 10: Select and scan or construct two images. Transition the first through at least three balanced variations to the last, (total of at least 5). Consider shape, object, scale, composition, complexity, and value among other factors in the transition. The differences (object presence, composition, value, color, detail, edge) in each of these elements should be no lesser or greater at any point of transition - all should transition uniformly and consistently.

Engineering Connections: Details cannot only affect how the image is perceived but how a device functions. Concepts of design and redesign, visual interpretation of data.

Aesthetic Connection: The discussion can include morphing animations in advertising.

Summary

There are fundamental parallels between the style and creative thought processes of Engineers and Visual Artists. In this paper we suggest that teaching the foundational concepts of Art, with disciplinary rigor and engineering context, will help improve critical and creative thinking, guide and encourage innovative engineering and visual art, and foster more effective direct and conceptual communication of scientific ideas and advancements.

The proposed course content, examples and concepts also provide some insight into the benefits of broader and more extensive cross-disciplinary cooperation between the two fields. A new paradigm of interdisciplinary interaction will provide enthusiasm, insight, and understanding – artists can afford to be more analytic and engineers can benefit by learning to see. We hope this paper provides some motivation for such collaborations. In either case we believe that both disciplines can benefit from the broader meaningful academic insight.

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