



CIRCE MAGAZINE: STEAM EDITION

FEATURING

The Art of Science *By Robert Root-Bernstein*

Colliding Worlds: How Cutting-Edge Science is Redefining Contemporary Art (Preface)

By Arthur I. Miller

Art and Science in a Transdisciplinary Curriculum *By Brett Wilson and Barbara Hawkins*

Leaning Out of Windows—Into Antimatter *By Randy Lee Cutler and Ingrid Koenig*

+ 18 additional articles on arts integration in science, technology, engineering and mathematics

CENTRE FOR IMAGINATION IN RESEARCH, CULTURE & EDUCATION,
SIMON FRASER UNIVERSITY



Editors: Gillian Judson & Jailson Lima

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Messages from the Editors

Welcome to CIRCE!

Imagination is central to human culture. Without it, no culture would look the way it does today, and no learner would be able to participate in and contribute to that culture. Nor would cultures change and evolve the way they do, in response to our ideas and our ideals, our ethical insights and technological innovations, were it not for imagination. And yet this essential human capacity is extraordinarily neglected in educational thinking, practice and research. This is what *The Centre for Imagination in Research, Culture and Education*, or CIRCE [sur-see], seeks to change.

Are you an advocate for imagination? Do you believe, as we do, that imagination is as important for learning in the Sciences as it is in the Arts? At CIRCE we believe that the imaginative engagement of students is as important at the post-secondary level as it is in primary classrooms, and as central to adult and community education as it is to online learning. We share Maxine Greene's conviction that imaginative development is crucial to the building of societies characterized by empathy and solidarity, societies genuinely inclusive of people from different backgrounds, of different abilities, and with different ways of seeing the world. And we also see imagination as deeply interwoven in the relationships between human beings and the rest of the living world.

These are issues of vital importance in the 21st century. We welcome collaboration and partnerships with researchers and educators around the globe who share these interests and are committed to expanding our understanding of imagination in research, culture and education, both practical and theoretical. So welcome to CIRCE!

It has been a great pleasure working with Dr. Jailson Lima to launch the CIRCE STEAM community and to co-produce this special CIRCE STEAM Magazine. I hope you enjoy this inspiring collection of STEAM at work in research, culture, and classrooms. If you haven't done so, please visit the CIRCE [STEAM page](http://www.circsfu.ca/practice/steam/) to get inspired and to get involved! (<http://www.circsfu.ca/practice/steam/>)

Yours in imagination,

Gillian

Gillian Judson, PhD

Executive Director, Centre for Imagination in Research, Culture & Education
(www.circsfu.ca)



Science is highly conceptual, and learning it effectively requires interconnecting *fuzzy* concepts such as atoms, forces, molecules, DNA, electric fields, ions, electromagnetic radiation, radicals, electrons, and photons. Although brilliant minds have undoubtedly used their artistic talents and been inspired by art over the centuries to create scientific knowledge, until recently we have catalogued its ramifications simply as STEM. In the last decades, movement has been made to rectify this limited worldview by expanding the acronym to STEAM.

As an educator who has been an enthusiast of Imaginative Education (<http://www.educationthatinspires.ca/imaginative-education/>) for over a decade, I had the pleasure of meeting Dr. Gillian Judson and the Imaginative Education Research Group (<http://ierg.ca/>) at Simon Fraser University in 2016. Last year, when Gillian invited me to join CIRCE, I immediately knew that I wanted to contribute to this initiative by working with STEAM. It has been a fantastic experience. We have contacted educators, artists, scientists, and STEAM policy makers who are passionate about the subject. This STEAM issue of CIRCE Magazine reflects the cohesive efforts of all participants. I have learned so much during the process.

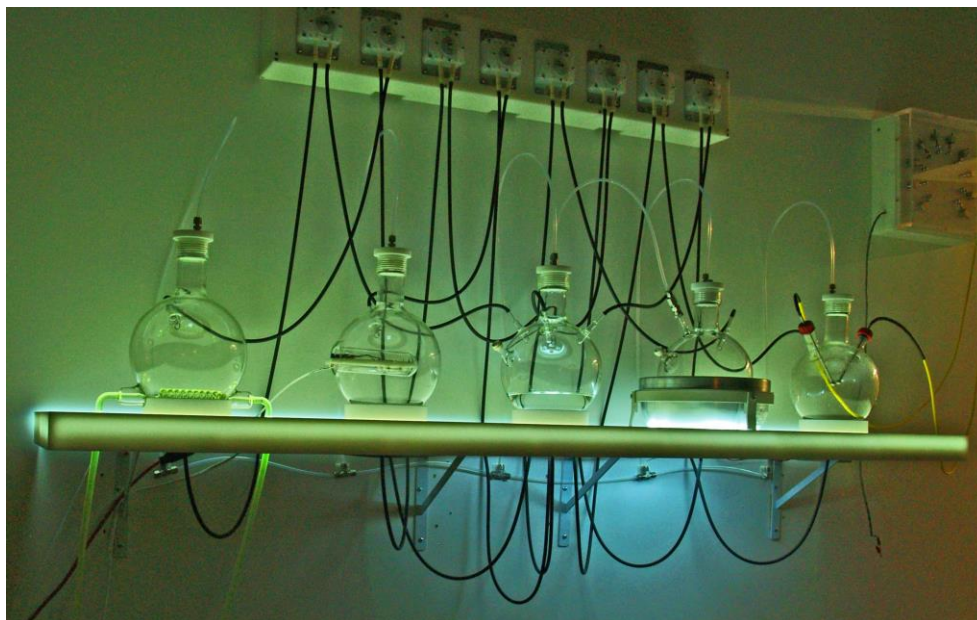
Despite the current inherent problems in the world, we are living in exciting times to imagine, explore, and create. I hope this is just the beginning of a new era where STEAM will become mainstream.

Sincerely,
Jailson Lima, PhD
Vanier College, Montreal



FEATURE: The Art of Science

By Robert Root-Bernstein



“ReBioGeneSys” Adam W. Brown and Robert Root-Bernstein at Zero1 Gallery, San Jose, CA, 2015 (photo by Robert Root-Bernstein). An art installation/performance piece that doubles as a functional origins-of-life experiment.

When I arrived at the Salk Institute for Biological Studies in La Jolla as a post-doctoral fellow in 1981, all sorts of rumors were circulating regarding Bob Holley. Holley was one of three men who had been honored a decade earlier with a Nobel Prize for the discovery and elucidation of the function of transfer RNA, the molecule that allows all living things to translate the genetic code into protein. Holley had since explored several other biological fields, and was currently working on growth factors—molecules involved in differentiation and cancers.

It was not Holley's laboratory work that was giving rise to the rumors, however; it was his extracurricular activities. Every Friday around lunch time a beautiful woman (not always the same one) would arrive at his office and Holley would accompany her into the private study which is one of the special perquisites of Fellows of the Institute. Holley and his guest would then spend most of the afternoon in seclusion. The way in which the Salk Institute is laid out, both the arrival of these beautiful women and the short trip to and from Holley's study were made in plain view of at least half of the Institute staff. Tongues wagged.

Holley's extracurricular activity was not what most people thought, but its nature was nonetheless surprising. The women were models posing for Holley's avocation of sculpting. Throughout the decade of the '80s, Holley turned out a series of lovely, sometimes lyrical, sculptures of ballerinas. He also began exploring sculpture as a form of portraiture. (My wife was one of his first subjects for these explorations). Worked in

clay, his sculptures were then cast in bronze, and some began to appear in his office, where the true nature of his activities became apparent. The pursuit of beauty, he told me, was one of the things that motivated both his art and his science.

I soon realized that Holley was not unique. My undergraduate advisor at Princeton, Bob Langridge (now retired from U.C. San Francisco) published an article comparing the aesthetic appeal of DNA structure to that of a rose window in a medieval cathedral. Roger Guillemin, an endocrinologist at the Institute and yet another recipient of a Nobel Prize, had a number of his water colors displayed on his office wall. (He moved to electronic media becoming one of the recognized founders of that medium.)

I also knew from reading broadly in the history of science that Louis Pasteur (inventor of the germ theory of disease) had been an extraordinary painter, as had Joseph Lord Lister (the inventor of antiseptics), Santiago Ramon y Cajal (perhaps the greatest neuroanatomist of the past century), Frederick Banting (the Nobel prizewinning discoverer of insulin), Wilhelm Ostwald (the 7th Nobel prizewinner in chemistry and the inventor of a still-popular color theory for artists), and Albert Michelson (the man who measured the speed of light and the United States' first Nobel laureate). Albert Einstein had played violin, of course; Max Planck had seriously considered a career as a professional pianist; E. B. Wilson, one of America's most important turn-of-the-century embryologists, was considered the best amateur cellist in New York; Martin Kamen, the man who had made carbon 14 dating possible, played viola at a professional level throughout his career; molecular biologist and Nobelist Jacques Monod had nearly ruined his scientific career by spending so much time playing and conducting music. Virginia Apgar, for whom the Apgar score used to evaluate the health of newborn infants is named, not only played music but made her own violins and 'cellos!

I began to wonder if there exists a significant connection between scientific achievement and an artistic bent.

My approach to the question of whether arts and sciences have any fruitful connections has taken two tacks. The first was anecdotal and basically historical. Through extensive reading of biographies and autobiographies, and by means of interviews, I have explored the incidence of combined scientific eminence and artistic talent. I have paid particular attention to what people who practiced both sciences and arts had to say about possible connections between their activities. Practical applications of arts to the sciences were high on the list of rationales for combining the two. Nobel laureate Alexis Carrel took lessons in lacemaking and embroidery in order to develop the manipulative skills and invent the suturing techniques that make possible open-heart surgeries and organ transplants. Art lessons explored the principles of symmetry necessary for Nobelist Dorothy Hodgkin to succeed in her field of x-ray crystallography. Mary Leakey, whose discoveries of primitive hominid skulls and footprints revolutionized anthropology had no formal training beyond archeological illustration, which taught her to observe much more acutely than her colleagues.

More generally, scientists often found the arts inextricable from their identities as scientists. Einstein said, "I think in music" and often found solutions to his physics problems at the piano keyboard. Entomologist and Pulitzer Prize winner Bert Holdobler wrote to me: "After high school I was first undecided whether I should study art or

biology. I have chosen biology and art became my hobby, only to realize during my university career that I can fulfill my artistic desires also in biology... A scientific publication should be a piece of art." Ethologist and surrealist painter Desmond Morris has written that his goal has been to combine "the imaginative and the analytical—artist and scientist—to be both at once." For, as Max Planck once wrote, "the scientist needs an artistic imagination."

Case studies are useful, of course, for demonstrating how the arts and sciences can work fruitfully together, but I also wanted to know whether such collaborations were rare or common. So my second approach to studying the subject has been psychological and statistical. The late Bernice Eiduson, a psychologist at UCLA, had begun a long-term study of the psychology of 40 young male scientists in 1955. When she died in 1988, my mother, Maurine Bernstein (who had been her research associate) and I took over the study. We examined the prevalence of various artistic hobbies among the group and, with the help of statistician Helen Garnier, correlated their success as scientists with their hobbies. We also explored with the scientists through interviews and a questionnaire whether there were connections between the ways in which they think about things mentally (e.g., visually, kinesthetically, abstractly, etc.), their success recognizing and solving problems, and their hobbies. Four of the scientists were eventually awarded Nobel Prizes; two others were nominated for Nobels; these six and another five became members of the National Academy of Sciences. We also had four scientists who did not obtain tenure and a reasonable pool of people who had undistinguished careers.

We found statistically significant correlations between the success of scientists (evaluated in terms of the ratio of citations of their work to their total number of published papers, on the one hand, and in terms of the number of high impact papers receiving more than 100 citations per year, on the other) and having one or more active artistic hobbies as adults. Success was also correlated with the diversity of mental tools these scientists employed. Scientists who used visual images, "acoustic images", kinesthetic feelings, and other unusual forms of thought were more likely to be successful than those who limited themselves to verbal, logical, and mathematical formulations of problems. Finally, the nature of the mental tools used by the scientists was statistically significantly correlated to their avocations and interviews showed that the successful scientists were aware of the connections and sometimes used them knowledgeably.

We followed up this original study with two very large-scale statistical studies. In one, we compared the incidence and types of avocations of all Nobel Prizewinners to those of members of the U. S. National Academy of Sciences and Royal Society, and to a non-selective group of scientists as well as to the U. S. general public. Overall, the more eminent the scientist, the greater the probability that she or he had an arts or crafts avocation. In the other study, we correlated avocations to various outputs such as numbers of papers, patents, companies founded, books published, etc. among a group of 237 successful scientists and engineers. Inventors and entrepreneurs were significantly more likely than their colleagues to have arts and crafts avocations and to be able to explain how their arts and crafts improved their scientific or engineering

work. We also found in this study that inventors and entrepreneurs were more likely than their colleagues to use visual thinking and modeling skills and less likely to rely on mathematical or verbal formulations of ideas. We have summed up our results by saying that artistic scientists have more image in their imagination; musical ones can duet (do it) better; craftsmen are more handy; and the creative writers have the skills to become the pundits of science. Seriously!

The importance of these results is manifold. First, they suggest that effective scientific thinking requires a complex mixture of many of what my wife, Michele Root-Bernstein, and I call in our book *Sparks of Genius* "tools of thinking." These consist essentially of observing, imaging, abstracting, patterning, analogizing, empathizing, dimensional thinking, modeling, playing, transforming and synthesizing. For example, a scientist may observe a discrepancy between theory and data, visualize a model of what that discrepancy means physically, imagine herself as part of that model to determine what parts of it are critical, and then convert the complex of visual images, models, and feelings back into a formal language that can be communicated relatively unambiguously (e.g. words and/or mathematics).

Secondly, we've found that some "thinking tools" are rarely used by the average scientist because they are considered to be "too subjective" or "artsy", but the most successful scientists and engineers often use these "tools" anyway. For example, many scientists emulate artists in empathizing with their subjects. Nobel laureate Barbara McClintock often talked about having a "feeling for the organism" while fellow laureate and physicist Hans Alfvén says he "becomes" electrons in order to understand their behaviors. Einstein similarly "became" a light wave while Desmond Morris imagined himself to be the animals whose behavior he wanted to understand. Novel ideas, these scientists say, do not come from logic, but rather from imagination, and at the level of imagination, scientists and artists think alike.

The difficulty that scientists (and artists!) face is how to translate their personal, non-verbal insights into forms communicable to other people, a process that they speak of as being an explicitly secondary stage in the process of discovery, after, as Nobel Prizewinner Richard Feynman once said, the visual images have been sufficiently developed. Oddly, then, our studies reveal that most scientific teaching occurs only in these secondary languages of words and equations, with little or no mention, and often less training, in the use of non-verbal, non-mathematical modes of thought or the importance of perceptual thinking tools, intuition and emotion. These are exactly the kinds of tools that artists have excelled at developing.

Indeed, our studies suggest that since most scientific education ignores non-verbal and non-mathematical forms of thought, the majority of scientists appear to have developed facility with such intuitive "tools for thinking" through artistic and musical endeavors, mechanical hobbies, or other pass-times. An unrecognized dependence of scientific education upon non-scientific skills may therefore exist that is being undermined as arts, crafts, and shop classes are eliminated from more and more schools. As one of my colleagues has asked rhetorically, "How are students in the future going to understand mechanisms if they never have the chance to take apart a spring-wound watch and try to put it together again?" Hand and body knowledge is as

important as mental knowledge as any experimenter knows. Intuition, both physical and mental, is developed only through experience with the world and arts are the disciplines that best train that kind of experience.

Another point we have been able to demonstrate is that these non-verbal, non-mathematical tools of thought can be taught. Einstein recounted the impact on his research of his high-school training in visual and kinesthetic thinking techniques (based on a curriculum developed by the great Swiss educator Pestalozzi). Nobel prize-winning physicist Luis Alvarez wrote about how his father, an eminent physiologist, purposefully enrolled Luis in a technical high school instead of the academic one, in order to train his hands as well as his mind. Alvarez claimed that his knowledge of how to think with tools was as important as his ability to use equations. And, as one final example, James Bonner, a biologist at Caltech who participated in the Eiduson study mentioned above, told about how he began college unable to "see" anything in his mind, but was taught to visualize and to physically model what was going on inside chemical reactions by his mentor Roscoe Dickerson. Such manipulation and visualization courses, which are now formal parts of the curriculum at M. I. T., Stanford and some other universities, are not uncommon components in the training of engineers as well.

The one thing that I have learned through all my studies is that all important discoveries, whether in the sciences or the arts, are synthetic. It should come as no surprise, then, that the thinking that creates innovations is also synthetic, transcending disciplinary ideas and integrating practices across perceived boundaries. Training scientists, technologists, engineers and mathematicians how to make such integrative, transdisciplinary leaps of imagination by training them in and with the arts is the first step in training them to innovate. We could do worse than to emulate the best of the best and they tell us that arts and sciences belong together!



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Since plastics are nonpolar, the expectation was that the interaction between the surfactant and the organic red pigment would improve its adherence and result in a uniform shiny red-colored plastic. However, the experiment had the opposite result: The pigment did not spread evenly in the plastic, whose appearance became even shabbier. I was flabbergasted: It did not make sense at all! After spending weeks trying to wrap my head around this unexpected outcome, I tried to *imagine* how these molecules interacted during the synthesis of the pigment. The surfactant was added after the pigment formed in water, and then the mixture was filtered and dried. Later, the dried powder was mixed with the plastic resin. But why, contrary to our prediction, did adding the surfactant make things worse?



By *imagining* the pigment and the surfactant interacting in water, I had an epiphany: Since the pigment was synthesized in water, the hydrophilic heads of the surfactant would naturally bind to water while the hydrophobic tails would be inserted into the pigment. Because plastic is nonpolar, it would not interact with the polar heads that were sticking out. That's why adding the surfactant made things worse! I speculated that synthesizing the pigment in a polar solvent like water was the origin of the problem. Since replacing water was not an option, I decided to add a tiny amount (1% of the total volume) of xylene—a nonpolar solvent—before adding the surfactant. The result was astonishing: the pigment spread evenly in the transparent plastic giving a bright, homogeneous, red color as was originally expected. Perhaps the rationale was so obvious that no one in the whole research group had thought of it before I came up with the proposal. The explanation was too simple: Polar fragments interact well with polar compounds but not with nonpolar ones.

Experiencing the power of imagery associated with imagination to solve complex problems like this was a transformative experience for me, and I started thinking about the shortcomings of my own schooling. Although scientific knowledge relies heavily on mental models and their visual representations, traditional approaches to teaching science are based mostly on algorithmic problem solving and procedural knowledge that

often neglect the crucial role of imagination in the learning process. I was taught in this traditional way and—despite believing in the power of imagination in learning—found it difficult to think outside the box to reinvent my teaching practice.

Decades later, I stumbled across Kieran Egan's ideas on Imaginative Education. Egan and his colleagues at Simon Fraser University's Imaginative Education Research Group (now the Centre for Imagination in Research, Culture and Education, or CIRCE) emphasize the crucial role of the narrative in providing engagement to knowledge. "A narrative is a continuous account of a series of events or facts that shapes them into an emotionally satisfactory whole" (Egan, 2005, p. 99). They propose a counter-intuitive, revolutionary idea: Instead of starting with what students already *know*, we should start with what they can *imagine*. The idea that imagination can open the doors of perception so that creativity and effective learning can occur spoke volumes and resonated well with my own beliefs and past experiences as a science student, professional chemist, and teacher.

Egan's books (Egan, 1997; Egan, Stout, & Takaya, 2007) gave me direction on how to develop both the curriculum and the instructional strategies employed in my science courses. Because of my interest in painting, the mention that artmaking fosters imagination made a powerful link with my past experiences with surfactants. I was able to solve the puzzle by creating an abstract painting of those molecules in my mind.

The art of painting aims to perfect vision, thanks to a pure visual perception of the outside world through the sense of sight alone. When a picture is conceived with this aim in mind, it is a means of replacing natural scenes where the eyes function mechanically, because of habit, which masks these sights which are always the same or always what we expect. (Magritte, 2016, p. 121)

The opportunity to explore imaginative approaches to teaching arose in 2009, the first time I taught *History and Methodology of Science*, a course for Liberal Arts students at Vanier College. I proposed a major assignment in which students used the visual arts to portray some of the scientific concepts studied in the course (Lima & Timm-Bottos, 2018). Over the years, I have tweaked the format by including asynchronous dialogues outside the classroom to flesh out ideas and bring concepts to the expected level of complexity (Lima, 2016). I also felt the need to include art labs (Lima, 2017) and sought the participation of art teachers in the process. After a couple of years working with Liberal Arts cohorts, I proposed a similar assignment in my General Chemistry, Solution Chemistry, and Organic Chemistry courses. Science students were asked to express the big ideas (Lima, 2016) and threshold concepts in Chemistry through visual arts, and they were required to write a rationale explaining the links between the course content and the visual representations in their final products. Examples of their artwork can be seen in Figures 2 and 3.

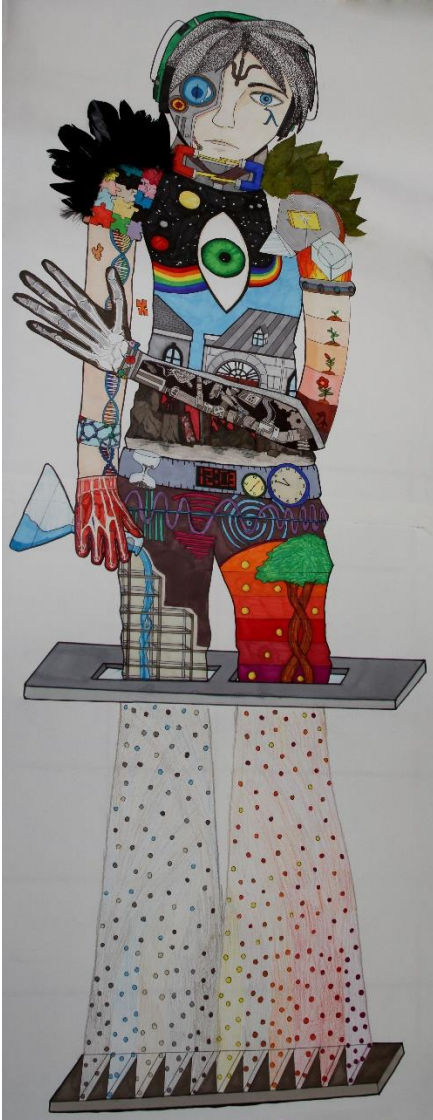


Figure 3: The Wonder of Science
(by Kristina Esposto, 2010)



Figure 2: Taste the Science! (by Jacklyn Di Genova, 2010)

The conceptual framework of this project was also inspired by the collaborative developmental studies conducted by Jerome Bruner (Efland, 2002; Gardner, 2006). Bruner outlined three ordered ways in which children represent the world: the enactive level (through action), the iconic level (through mental imagery), and the symbolic level (through the manipulation of symbols). Although early childhood education curricula intertwine a variety of learning strategies from these three ordered levels, similar approaches are not available in the teaching of science at the college level. It seems that teachers (especially those in the natural sciences) have been trained to look down on imaginative approaches for students who are older than toddlers, as if imagination is inferior to rational, Cartesian thought. Instead of starting with the iconic level, traditional approaches overemphasize symbolic representation, which leads to rote learning. In the traditional teaching of science, it is way too common to mistake the ideas for their symbolism: Being able to read the symbols has no direct correlation with reaching the knowledge they represent. As Greene (1995, p. 74) points out:

What seems crucial is...the active insertion of one's perception into the lived world... To ponder this is to become convinced that much of education as we know it is an education of forgetfulness. Distracting the young from their own perceived landscapes and shapes, we teachers insist on the givenness of predetermined explanatory frames. We loosen the connections between the young and the objects, images, articulations, and other people with which they have been enmeshed.

Asking students to portray abstract chemical concepts such as atomic models, energy, or chemical bonding using visual representations nurtures their imagination and creative thinking skills. Representing scientific knowledge at the iconic level might help them make the transition from the abstract to the concrete. The abstract character of the visual arts has the potential to open a window onto the invisible world of chemistry by providing new insights and shedding light on counterintuitive scientific concepts that stem from formal, conceptual structures that do not arise spontaneously in the everyday experiences of learners. This reflects the necessity of academic concepts to be linked with spontaneous concepts as shown in the grassroots works of Vygotsky (Connery, John-Steiner, & Marjanovic-Shane, 2010), Dewey (Jackson, 1998; Taber, 2009), and Freire (1998).

By envisioning learning as an interpretive, recursive, nonlinear building process accessed through physical and social interactions, the STEAM curriculum can combine images and narratives that connect one's imagination and identity to the course material. This might be especially useful for learners who are struggling to form a cohesive map of science in their minds. Including art in STEM might help science students see the world in new ways and enlarge their intellectual profile (Gardner, 2006) beyond the prevalent logical-mathematical and verbal-linguistic domains that are commonly explored in science courses.

There is a misconception that creativity in school is only about artistic expression (Resnick, 2017). The inclusion of art in STEM entails more than seeing and creating objects that appeal aesthetically. Instead, art informs the world in unique ways by developing creative thinking while refining perception to enhance understanding (Eisner, 1998). The process of artistic creation requires active engagement, imagination, trial-and-error, the ability to integrate concepts, and the use of higher-level cognitive domains. Those skills are useful as illustrated by the story at the beginning of this article: Job markets are constantly expressing their need for creative workers who can think outside the box and propose innovative approaches to grapple with new challenges.

Due to the stringent character of the science curriculum, not enough time is allocated to explain the role of imagination in developing groundbreaking theories such as Faraday's electromagnetism and electrochemistry or Einstein's Relativity. By omitting the paramount importance of imagery in developing scientific models, schools reiterate the false dichotomies that science and art as well as imagination and reason lie in opposition to each other. These misconceptions also reinforce the dualistic view of knowledge possessed by most college students since, instead of emphasizing the intrinsic limitations of models, teachers often present the scientific method as an almost infallible way of knowing. At this level, students tend to believe that scientific knowledge represents an absolute truth and that scientific discoveries are the result of a mere flash of insight of extremely gifted individuals (Resnick, 2017) rather than being part of a slow and meticulous process.

Luckily, in the last decades, the connections between art and science (Castel & Sismondo, 2008; Henderson, 2008; Kandel, 2016; Lemons, 2017; Miller, 2000; Parkinson, 2008) and science and imagination (James & Brookfield, 2014; Kandel, 2012; Roche, 2010; Root-Bernstein & Root-Bernstein, 1999; Vignale, 2011) have received a

great deal of attention as attested to by the growing number of publications on the topic. The ambition of developing a STEAM curriculum that nurtures imagination and creative thinking on a national scale is achievable. It can be a powerful tool to engage 21st-century students with a world in flux as they construct knowledge in a meaningful way.

Engagement in the arts ... seems to place the individual in another world. Aesthetic satisfactions ... enable a person to lose a sense of distance and time; one seems to occupy a spaceless and timeless universe that in retrospect yields high degrees of satisfaction. (Eisner, 2002, p. 202)

We need creative individuals to find solutions to the serious societal and environmental problems that humans are currently facing. The inability to attract students to science is a trend that has been observed worldwide and has become a serious threat to keeping up with the necessary technological innovations of today's world. At a time when creativity is needed more than ever before, it is worthwhile to explore the multiple facets of the STEAM curriculum to enhance the quality of instruction by providing more interactive, engaging, and rewarding lessons.



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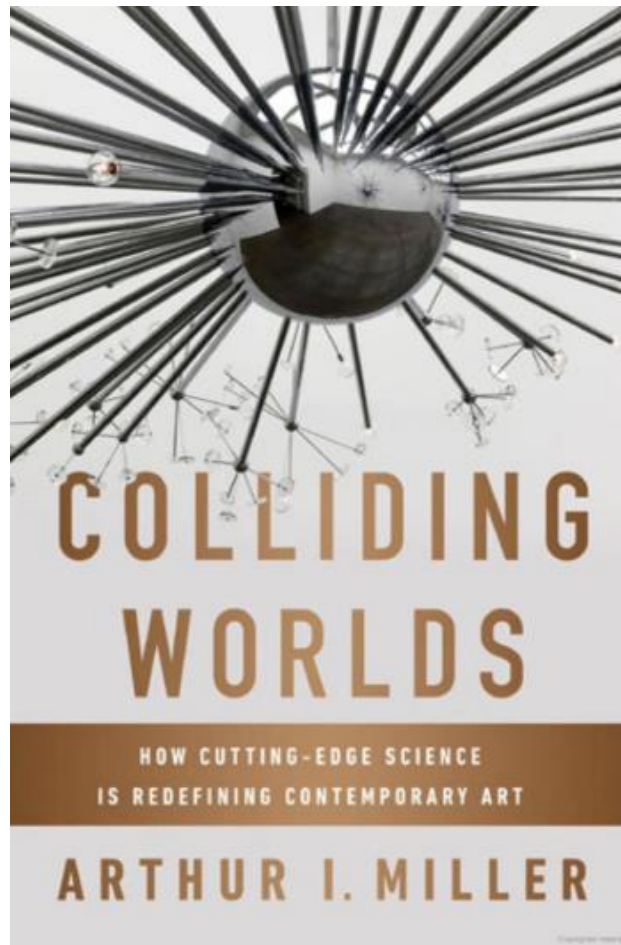
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Colliding Worlds: How Cutting-Edge Science is Redefining Contemporary Art (Preface)

By Arthur I. Miller

Preface reprinted with permission from Miller, A. (2014). *Colliding Worlds: How Cutting-Edge Science is Redefining Contemporary Art* (New York: W.W. Norton) (<https://amzn.to/2OSENpf>)



On October 13, 1966, the New York glitterati and all those who basked in their glow descended on the cavernous 69th Regiment Armory on Lexington Avenue to celebrate the opening night of *9 Evenings: Theater and Engineering*, the first ever large-scale collaboration between artists, engineers, and scientists. Ten artists and thirty engineers took part and the technology they used was spectacularly new at the time.

Naturally Andy Warhol, in sunglasses and leather jacket, was there, surrounded by his entourage. He was heard to declare, "It's just great." The Beat poet Allen Ginsberg was approached by a young woman who whispered in his ear, "You probably don't remember me, but I'm Susan Sontag." Marcel Duchamp, who had kick-started the entire

modern movement in art, was there too, no doubt remembering the moment fifty years earlier at the 1913 Armory show when his *Nude Descending a Staircase* had scandalized New York. The up-and-coming artist Chuck Close sat next to Duchamp. The fashion designer Tiger Morse wore a bare midriff outfit of white vinyl with a portable lamp which bathed her in a violet glow.

Everyone involved agreed that Robert Rauschenberg was the inspiration but John Cage was undoubtedly the star. Cage, the composer famous for his 4'33"—four minutes and thirty-three seconds of intense silence—produced a collage of sounds randomly collected at that moment by telephones around the city and the Armory. As the performance went on, one by one members of the audience stepped onstage to add to the cacophony, playing with juicers and mixers installed there.

The following night, Rauschenberg, the celebrated iconoclast and artist, showed a piece called *Open Score*, basically a game of tennis with the rackets wired to transmit sound. Every time a racket hit a ball, an amplified “boing” resounded around the building and one of the forty-eight lights went out, until the audience was in total darkness.

The performances were by turns magical and chaotic. It was an Andy Warhol moment, although very much inspired by Duchamp. The two served, so to speak, as bookends, Warhol as the logical conclusion of Duchamp—from the ready-made to the Campbell's soup can. Everyone was sure what they were seeing was a brand new art movement that was going to blow a hole right through the middle of the traditional art scene—and they wanted to make sure they were in at the beginning. The opening night was a sellout, with 1,727 tickets sold; 1,500 people had to be turned away. In all, 11,000 people attended, with sellouts on three of the nine evenings. Everybody who was anybody, or had dreams of being somebody, was there to bask in the glow of the already famous. A *New York Times* reporter wrote of a sold-out performance, “A bomb dropped here would turn off the whole New York art scene.”

In the nearly half century that has passed since that first explosion of excitement, art, science, and technology have rubbed up against one another in myriad ways. The resulting artworks have been sometimes beautiful, sometimes disturbing, sometimes subversive, sometimes downright crazy, but always interesting, new, and pushing the boundaries.

Colliding Worlds begins by taking the story back to the early days of the twentieth century, when inventions such as x-rays and photography transformed the way we see the world. Artists such as Picasso and Kandinsky took on board the latest scientific developments, while scientists found themselves driven by questions like the relevance of aesthetics to science and what makes a scientific theory beautiful. But it was not until the second half of the last century that the new movement, which has come to define the twenty-first century, really flowered, and it is this flowering that forms the bulk of my story. Its creators are artists and scientists working together to create images and objects of stunning beauty, along the way redefining the very concept of “aesthetic”—of what we mean by “art” and, eventually, by “science.”

I started to write about how art interacts with science and technology in the 1980s, when few people other than the artists and scientists themselves were taking

note. Over the years I watched as more and more artists emerged, along with more and more art fairs and more and more conferences. I watched as the movement grew from something underground to something far more mainstream that impinges on our daily life, the realm of what we all take for granted.

Full of curiosity, I began to track down and talk to those involved. I learned who these artists are, why they decided to become artists, what it meant to collaborate with scientists, and what their notions of aesthetics and beauty were in this strange and constantly evolving terrain—the avant-garde of the twenty-first century—and began to put together these dispatches from the edge of art and science. I discovered that the artists I spoke to are all engaged in the same quest: to find a way to unite art, science, and technology.

I looked for leading artists working in all the different areas of the new movement. I've limited myself to artists whose works illuminate science and might even contribute to scientific advances. I am less interested in those who simply use science to illustrate their themes. Although the results can be dazzling, they don't reflect back onto science or technology. Some of the artists I spoke to collaborate with scientists, others have learned at least some relevant scientific concepts, while others are both artists and scientists—artists who are also researchers.

To my surprise, collaboration between artists and scientists turned out to be a minefield. Is it always the artist who benefits, and not the scientist? Does a scientist's everyday research benefit from such collaborations? These are topics that came up again and again in the course of my research.

Initially I sought out these new-wave artists via galleries and museums. But the avant-garde has never been welcome in the traditional art world. Instead, these artists have created support networks of their own. They meet at international biennales and regular gatherings devoted to celebrating and exhibiting the latest creations in science-influenced art. Foremost among these are Ars Electronica in Linz, Austria, Zentrum für Kunst und Medientechnologie (ZKM) in Karlsruhe and Documenta in Kassel, both in Germany, the Science Gallery in Dublin, Le Laboratoire in Paris, CERN in Geneva, and the Wellcome Collection and GV Art in London. The School of Visual Arts (SVA) in New York focuses on science-influenced art, as do the MIT and NYU media labs, and there are departments devoted to it at the Slade School of Fine Art and Central Saint Martins in London, among others.

I also scoured scholarly papers and newspaper and magazine articles and books such as Edward Shanken's *Art and Electronic Media*, Bruce Wands's *Art of the Digital Age*, and Stephen Wilson's *Art + Science Now: How Scientific Research and Technological Innovation Are Becoming Key to 21st-Century Aesthetics*. They all provided interesting overviews of the subject but made no attempt to convey the people behind the art: their creativity and what drives them, their dreams, their struggles, the drama of developing a new art movement and what it is up against. To look deeper into all these topics I've chosen to interview some of the artists, scientists, and engineers who are actually involved.

One last problem is what to call this art form that is influenced by science or technology. Terms such as "artsci," "sciart," and "art-sci" seem inadequate to convey its

beauty and subtleties, though I've opted for the first. I have no doubt that in the future these works will become known simply as "art." [Preface from: Miller, A. (2014). *Colliding Worlds: How Cutting-Edge Science is Redefining Contemporary Art* (W.W. Norton).]



Arthur I. Miller is the author of many critically acclaimed books on creativity in art and science, with a new book on AI and creativity in art, literature and music to be published by MIT Press in fall 2019. For more information see www.arthurimiller.com and <http://www.collidingworlds.org>

Art and Science in a Transdisciplinary Curriculum

Brett Wilson and Barbara Hawkins



I am enough of an artist to draw freely upon my imagination. Imagination is more important than knowledge. (Einstein, 1929)

The 'Project Dialogue' approach to pedagogy

The transdisciplinary research group 'Project Dialogue' (www.projectdialogue.org.uk note: website currently under re-construction) was established in 2006 in the former Department of Art & Design at the University of the West of England (UK), where one of the authors (BH) was head of the Postgraduate School. As long-term collaborators, the founder members (Barbara Hawkins—arts educator, Brett Wilson—scientist, Stuart Sim—philosopher and Iain Biggs—

artist and cultural theorist) had developed an appreciation of the fundamental conceptual models, structures and metaphors underlying each other's disciplines, and used this to promote a transdisciplinary forum exploring research questions across the arts, sciences and humanities.

Since its inception, Project Dialogue has employed a number of different ways of working—medium-sized transdisciplinary symposia, small research teams working with other centres on specific topics, and seminars/workshops with doctoral and master's students. The flexible nature of the group's wider associate membership has encouraged collaborative endeavours, resulting in journal and conference papers, a book (Wilson, Hawkins, & Sim, 2014) and a variety of arts practice exhibitions. The consistently positive responses to our seminar and conference contributions from young postgrads and early-career researchers, alongside the growth of membership of Project Dialogue, confirmed for us that there is a genuine intellectual appetite among the emerging new generation of academics and practitioners for a broader transdisciplinary curriculum.

An early example of Project Dialogue activity within our own department consisted of a series of fortnightly seminars shared between Hawkins and semi-retired scientist Wilson as 'Scientist in Residence.' At the time, many of our own arts-practice doctoral and masters students were developing research interests embracing both art and science and felt they needed a deeper understanding of methodologies 'from the other side.' Participants included fine artists, printmakers, graphic designers, glass and ceramic artists and other craft practitioners alongside researchers from the physical, natural and neurological sciences. Our forum offered structured opportunities for this diverse collection of students to explore many of the often-hidden underlying concepts, assumptions and metaphors that their own and other disciplines were built on. Questionnaires confirmed that participants felt that our 'history of ideas' approach had worked very well and that they were in a much better position to engage across the art-science divide with greater creative confidence and insight.

Following the workshops, students began to appreciate how both art and science employ many overlapping forms of critical thinking, creativity and imagination when trying to understand the world, and that their roles as *practitioners directly engaged in research* could provide an identity stronger than just the narrower traditions of their own individual fields of practice. A transdisciplinary teaching approach benefits not only students but can also help overturn staff misconceptions by inviting them to work with other practitioners from dissimilar backgrounds. Working subsequently with students and staff in other settings, we witnessed this effect first-hand as a new broader language of discourse developed in the studio, lab and seminar room.

Transdisciplinarity in action

Education should help prepare us as individuals, cultural agents and societies for a future which will always be to some extent unknown—no matter how hard particular government-inspired policies may seek to engineer specific ends. Yet modern curricula in higher education courses are far too narrow to give participants (either students or staff) sufficient breathing space to explore beyond fairly rigid and conventionally-determined boundaries. The benefits to society of supporting a new generation of researchers who are capable of and enthusiastic about the prospect of examining many of today's complex issues through a collaboration of

methodologies, expertise and knowledge bases cannot be underestimated. Whilst it is encouraging to see an increase in the number of schemes that fund arts practitioners to work as ‘artists in residence’ across academic disciplines, it is disappointing that the number of ‘scientist in residence’ schemes of the type introduced by Project Dialogue are exceedingly rare.

Postgraduate students and early-career researchers, with their enthusiasm and curiosity to find novelty, are perhaps less hidebound by old disciplinary traditions and are certainly capable of developing significant innovation in their endeavours. However, too often they can be intimidated by the obstacles they face when challenging the largely discipline-specific environment in which they study and work. During a period of increased interest in the crossover between arts, humanities and physical and natural sciences, preparing students for transdisciplinary research projects must become an integral part of doctoral education. This ambition, however, implies challenges for both individual academics and the institutions within which they work.

Institutional challenges

Encouragement and support for a curriculum that nurtures transdisciplinary talent and expertise are vital for a successful transformation of the way in which we traditionally view disciplinary domains and boundaries. It is important that institutions offer the time and opportunities researchers need to assimilate the methodological subtleties of their potential transdisciplinary partners’ domains. Such support would create more agile and imaginative cross-connections among like-minded researchers and practitioners—such as with the now well-accepted hybrid research base of cultural and economic geography, for example.

Courses that examine and compare the methodologies and techniques employed by artists, scientists and those from the humanities would foster understanding of the processes and outcomes across disciplines and serve as an introduction into a wider research community for postgraduate students. Such a curriculum would promote a student-centred model of pedagogy which redefines transdisciplinary lecturing staff and doctoral supervisors as facilitators, collaborators and co-creators of knowledge. Academic staff must also be prepared to make changes, as supporting students in a transdisciplinary research environment requires a degree of academic humility and self-reflection more in line with Anderson’s (2006) analytical auto-ethnographic approach.

The creation of an institution-wide Transdisciplinary Research Centre (TRC) with a remit to nurture, support and encourage transdisciplinary scholarship and practice offers an attractive route forward. Such a centre could consist of a small number of full-time staff with sufficient budget to ‘buy in’ academics from different departments for mentoring, seminar programmes and supervision, and also to offer bursaries to prospective doctoral students submitting transdisciplinary proposals.

The Centre could provide:

- Training programmes for early-career researchers interested in developing a transdisciplinary research profile;
- Training for doctoral supervisors to build the skills needed to co-supervise transdisciplinary research projects;
- A meeting place for academics (and members of the public) to discuss potential collaborations across disciplines and share insights;
- A data-base of peer-reviewed publishing outlets for scholarly work and transdisciplinary practice;
- A comprehensive postgraduate curriculum designed to enhance transdisciplinary understanding and methodology.

This curriculum could include:

- Residential weekend or short summer schools bringing together diverse groups of doctoral students to work on topics spanning a number of disciplines;
- Modules delivered by staff from departments in the sciences, arts and humanities designed to explore a 'history of ideas' from multiple perspectives;
- Seminars designed to build confidence in presenting ideas to non-specialist audiences and potential employers;
- Guest lectures from transdisciplinary practitioners discussing their methods and approaches;
- Workshops designed to explore the nature of public engagement, social entrepreneurship and commercial opportunities for transdisciplinary project outcomes.

A TRC of this nature would create much-needed encouragement and support for a new generation of doctoral candidates and an environment in which emerging transdisciplinary scholars could flourish and communicate their findings without fear of career stagnation. Over time, the centres would be able to build a rich pool of senior academics, better equipped to supervise, support and examine the outcomes and findings of transdisciplinary research students. Involving academics from across an institution's various faculties also offers opportunities for more established discipline-focused academics to explore the potential of new ways of operating in a spirit of genuinely open intellectual experimentation.

Institutionally, a TRC would provide a distinctive auditable base for a range of transdisciplinary research outcomes such as team-based publications, software tools, ArtScience works and partnerships with industrial and community ventures. Transdisciplinary research, by its very nature, opens up exciting and stimulating motivations for researchers from many disciplinary areas, with valuable opportunities for collaborative enterprise and knowledge-transfer activities through a network of industrial partners willing to host research placements exploring broader approaches to problem-solving.

For a future generation of research academics to become sufficiently intellectually agile and play a meaningful role in creating sustainable solutions to complex global problems, institutions must evolve new ways of educating, training and mentoring postgraduate

students to instil the confidence they need to operate across disciplinary domains. Centres of the type described above would offer a fruitful intellectual and financially viable route through an increasingly complicated research landscape.

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The second section of our paper offers a highly condensed outline of material taken from seminars developed for mixed groups of arts, science and humanities master's students as part of the transdisciplinary 'history of ideas' element within their study program. These seminars introduced many students to topics previously not encountered and were highly successful in encouraging a healthy debate.

Enlightenment separation of Science and Art

One of the most significant disciplinary divisions over the last century has been between science and art. Science is usually portrayed as detached, objective and logical, whereas art is popularly seen as creative, subjective and emotional. In these traditional forms, they often appear to be completely incompatible and based on immiscible modes of enquiry. However, these distinctions are increasingly being challenged as we seek a deeper understanding of how we as humans perceive, conceive and interact with the world and each other. As eminent physicist Brian Cox stressed when presenting the Royal Society's 2016 book prize for Andrea Wulf's biography of Alexander von Humboldt (*The Invention of Nature*), "[...] Moreover, he [Humboldt] was a polymath who was curious about everything and was a superb communicator. *His interdisciplinary approach puts paid to the ridiculous notion that science and the arts are separate entities.*" (Cox, 2016. Emphasis added.)

Scientists depend just as much as artists on learning how to look and conceptualise. Scientific 'looking' has a history that can be studied; a history that encompasses far more than just the idea of objectivity (Kemp, 2006). Notions of objectivity were only adopted in scientific enquiry around 1830, following the previous 'truth to nature' standpoint of the Romantic era, and only lasted for just over a century before evolving into current idea of 'expert judgement' (Galison, 1998). Regrettably, few science students are taught that the visualisation of concepts that are essential to their subjects is so strongly rooted in contemporary conventions, or that, "... scientific knowledge is not absolute, but is instead based on mental models that have intrinsic limitations to their applicability." (Lima & Timm-Bottos, 2018).

Cartesian duality and disembodied realism

So how do we as individuals know and experience a world external to ourselves? Integral to this question is whether we consider our mind and its conceptual processes to be somehow different and separate from our physical brain, body and the outside world (i.e. disembodied), or whether we consider the processes of thinking, reasoning and experiencing to be intimately connected to our physical brain and body (i.e. embodied). Descartes drove a firm wedge between the mental faculties of a reasoning mind and the experiences available via a physical body and the world in which it is situated (Cottingham et al., 1988). His notion of mind-body dualism and the consequential subject/object dichotomy effectively made it impossible under western analytic philosophy to discuss any qualities or values that art and

science might share, since they had been cast as orthogonal domains: the one never able to illuminate the other.

Significant refinements to our understanding of scientific theories appeared during the 20th century from Popper (1959) and Kuhn (1962), the former a proponent of falsifiability in the form of testable predictions as the major criterion of a good theory, while the latter gave us terms such as “paradigm,” “normal science” and “scientific revolution” to enquire into the socio-epistemology of theoretical reformulations and their acceptance. Popper’s falsifiability criterion is still employed today as our best approach to evaluating competing scientific theories. Whilst the nature of scientific theories has been studied for some time much less attention has been paid to how our imagination helps us create such wonderful—and at times quite bizarre-sounding—theories in the first place. Recently, however, second-generation cognitive science and imaging technologies have revealed tantalising glimpses of the cognitive mechanisms by which artists and scientists see their respective worlds, and which show that they are probably not so different after all (Carrier, 2011).

Kant maintained that we cannot make theory-neutral observations; a point echoed by Einstein, “It is the theory which decides what we can observe” (Heisenberg, 1971, p. 63). The new quantum world that Bohr, Einstein, Heisenberg and Schrödinger argued fiercely about in the 1920s wasn’t simply discovered as a self-contained and ready-packaged entity; it took many decades for world-class scientists to create and refine the conceptual models required to make sense of it. The quantum world as we understand it today is just as much a crafted product of human imagination as it is a physical one. Fundamental scientific research is therefore also dependent on *a priori* cognitive and linguistic frameworks of one form or another, without which we cannot know anything definite about the external world or undertake detailed experimental work.

The role of metaphor in science

How are we to reconcile the strictly literal elements of science required for dealing with the physical world with the more imaginative aspects required for constructing new conceptual models and theories? This is an important question as we seek imaginative new theoretical concepts to explain the intangible mysteries of dark matter and energy.

Intriguingly, even though science is clearly concerned with literal truth, the underlying conceptual models from which these predictions emerge are almost certainly metaphoric in nature (Wilson, Hawkins, & Sim, 2015). Whilst metaphors enrich our verbal and written communications and act as powerful linguistic techniques across the arts and humanities their role in scientific creativity isn’t immediately obvious. Lakoff and Johnson’s (1999) work on embodied realism, which links our powers of metaphor-infused thought and imagination to our sensorimotor faculties and experiences, helps illuminate why this is so, and why non-literal modes of representation are required even when dealing with the physical world. They argue that metaphorical content holds true in that the cognitive content of the metaphor, in distinction to its literal meaning, can be considered valid by virtue of successful mapping from one domain of experience onto another. Our bodily experiences are a uniquely powerful influence on our thought processes, providing virtually all of the domain content for one side of nearly all cognitive metaphors. For example, ‘*Seeing the point*’, ‘*grasping your meaning*’,

‘*illuminating* the problem’, and so on being usages drawn from the bodily experience of vision and touch projected onto the realm of pure cognition.

Steven Mithen (1996) maintains that conceptual metaphors are an essential part of the mental toolkit modern humans have evolved over their pre-historic ancestors to support abstract thought in general and that metaphors permeate our thoughts to the unconscious level to the extent that they actually underpin many of the concepts that we pre-reflectively take as literal. In *Metaphors We Live By*, Lakoff and Johnson (1980, p. 6) agree “... human *thought processes* are largely metaphorical” and that “... the human conceptual system is metaphorically structured and defined.”

All metaphors, even the very simplest, display one essential characteristic: they cannot be literally true. (e.g. King Richard *is* a lion in battle; King Richard is human, not a lion). Metaphors are always *literally* false, but yet true in some different non-literal sense that benefits our understanding by offering a new and unexpected viewpoint from which to contemplate the topic under discussion. More sophisticated use of metaphor—as in Shakespeare’s comparison of Juliet to the sun; bringer of emotional life through her warmth, light and vitality, for example—still displays this crucial non-literal feature. It is evident that truth conditions become strangely irrelevant where metaphors are concerned, as Hagberg (2005, p. 373) points out, “... metaphoric expressions seem to propose a way of seeing the world, a distinct perspective upon it, rather than making a true-or-false assertion.”

The figurative language of metaphors and analogies clearly help scientists—and everyone else—to link experience, intuition and imagination when erecting conceptual scaffolding (an obvious metaphor, of course) for advancing into new realms of the ‘not-yet-known-or-experienced’ where literal language on its own is often insufficient to fuel and sustain imagination. A well-chosen scientific metaphor is capable of creating understanding in a way that literal language often fails to do and can illuminate fertile new directions for study, until it is eventually accepted as the core of a predictive theoretical model. As Brown highlights (2008, p. 73), there are numerous historical examples of visual metaphors forming the basis of predictive models in the physical sciences, from Bernoulli’s billiard-ball model of gases to the planetary model of the atom. Chemistry makes wide use of ball-and-stick models for molecular structures, along with the more comprehensive version built around space-filling chemical molecular models and orbital overlapping.

Scientific theories as metaphoric equations

All ‘new ways of seeing’ produced by newly-created scientific models are actually generated through novel metaphoric viewpoints rather than literal truth tests. Literal truth tests are of course vital for judging the merit of any new theory through painstaking and detailed experiments, but they cannot be performed directly on an underlying metaphor, only on a model’s predictions in the physical domain. By virtue of transformational mapping between the embodied cognitive domain and the external physical domain a scientific theory essentially functions as a metaphoric equation, permitting us to look beyond what (Wilson, 2017) terms the “logical event-horizon” of literal descriptive truth.

In effect we are creating a virtual equation linking our internal mental schema of conceptual models and the external physical world of verifiable experiments via falsifiable predictions from its associated mathematical formulation. The nature of the test is different

on each side of the equation: metaphoric ‘truth’ (such as unexpected insight) on the cognitive side; literal truth on the physical side. A brilliant new theory functions well in both domains and in doing so ushers in a fresh paradigm through its new way of seeing, as with Einstein’s relativity, for example. Each new sustainable paradigm will always have at its core a new and unique metaphorically-inspired conceptual model. Kuhn’s ‘revolutions’ in science are essentially metaphoric revolutions that create new theoretical landscapes (and language) for viewing scientific phenomena, both existing and as yet unimagined. Deductive logic and experimental rigour are the puzzle-solving tools science uses to judge these conceptual models; not tools for creating them.

Metaphors can be both pervasive and subtle in relation to how we create and think about science’s underlying conceptual models and our fundamental sense of scientific reality. They have become widespread in the biological sciences, with immunology leaning on them particularly heavily, for example: medicine as a *war* against disease with the immune response as the *first line of defence* being a widespread figurative choice. Combat metaphors are not the only ones used in immunology, but they are certainly amongst the most prevalent, even in medical textbooks and research papers.

Metaphors in science are important in forming conceptual models, but an unwise choice can hold back science either directly (because an unproductive path is followed) or indirectly (because alternative paths are not explored). Our earlier culturally-based gender-stereotyping of the active male sperm penetrating a passive female egg probably delayed work on how the egg actively participates in the process of fusion and fertilisation. Similarly, growth of a new generation of research programmes in developmental dynamics (many associated with stem-cell research) was encouraged partly because the Human Genome Project indirectly brought about a rethink to the earlier deterministic image of Dawkin’s ‘selfish genes’ (Keller, 2000).

Conclusions

In this paper, we have explored some of the underlying cognitive and conceptual factors linking art and science and examined how an arts-enhanced STE(A)M curriculum would help create a new generation of better-informed practitioners capable of re-imagining both old and new problems. Our present narrow attitude to science and technology means we have made too many questionable choices for our planet and its inhabitants. We urgently need a new generation of environmentally aware techno-scientists who will not unthinkingly perpetuate these mistakes. And for that they need a far bolder education—the sort of education that STEAM can help provide.



After retiring from his scientific career, Brett Wilson moved to an Arts faculty to further his interests in philosophy of science and transdisciplinary education.

Barbara Hawkins is a recently-retired UK academic who continues to publish in the areas of Art, Media and Design.

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Leaning Out of Windows—Into Antimatter

Art and Physics Collaborations Through Aesthetic Transformations

By Randy Lee Cutler and Ingrid Koenig



Robert Bean (*Air Conditioning*, 2017)

Leaning Out of Windows (LOoW)¹, funded by a SSHRC Insight grant (2016 to 2020) is an art and science collaboration in the form of hybrid research and a long-term curatorial initiative.² In *Leaning Out of Windows* artists and physicists are brought together to share the quest to understand the nature of reality. The aim of LOoW is to transform the grammar of abstract knowledge by specifically addressing the barely discernible phenomena studied by physics through aesthetics, analogy, metaphor, and other inventive methods. The project has four phases in which to coordinate, curate, assess and analyze models of collaborations between Emily Carr University and TRIUMF, Canada's particle accelerator centre. What is shared is a space of mutual inspiration informing each other's work in the search for new and emergent understanding. Our research creation questions are twofold. In what ways can transformative methodologies of collaboration work to engage with the diverse languages employed by artists and physicists? And what are possible models for interdisciplinary learning in the studio and science lab that are creative and effective generators of new knowledge and its visualization?

LOoW is interested in the constellation of connections, energies and conceptual engagements that inform the project. Beyond individual artworks, what does the web of artworks

¹ leaningoutofwindows.org

² Collaborators include physicists Dr. Jonathan Bagger Director TRIUMF, Dr. Reiner Kruecken Deputy Director TRIUMF, Lisa Lambert TRIUMF, Dr. Tim Meyer Fermilab, Elvira Hufschmid ECU, Dr. Margit Schild ECU/UdK, Dr. Ursula Brandstaetter ABPU

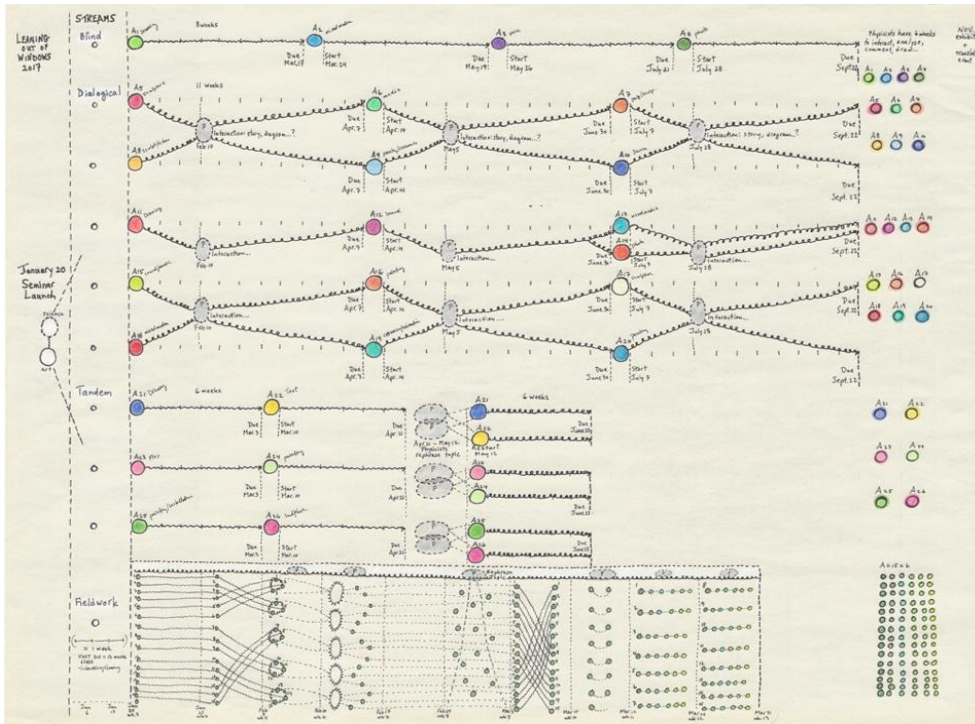
tell us about the response to a science topic? How does interdisciplinary collaboration generate what we are calling hybrid research, co-thought and distributed cognition? We see this process as transformative methodologies of collaboration that generate new knowledge and its visualization. As philosopher Elizabeth Grosz posits: "...in drawing on the other's resources each must transform the work of the other into its own language and its own purpose" (CTA 2008, 61).

The groundwork for these Art and Science interactions was a Process Design Workshop in October 2016 that included scientists from TRIUMF, artists from Emily Carr University as well as graduate and undergraduate students from both institutions. This first collaborative event set the stage for how we might work with each other developing what collaboration and co-thought might mean for us. We learned ideas about diagramming, visualizing data within the discipline of physics and ideas about creativity. Importantly the process developed and informed our working relationship with each other. We discussed what creativity means within our respective realms and how ideas are communicated amongst a group of very diverse thinkers. During follow-up meetings we took ideas raised in the process design workshop and developed them further sharing observations on metaphor, creativity and communication in our respective disciplines. We also considered language and how different our understanding was of terms such as elegance, beauty and symmetry. Developing this working relationship and trusting each other was foundational for learning how we would communicate with each other for the next four years. During these meetings one of the scientists made the comment that this wasn't a fishing trip, in other words that we weren't looking for new ideas or what we wanted to learn. At this point we realized that in fact these meetings *were* fishing trips, that we were looking for new ideas, what we wanted to learn and innovative ways to design the process.

After many meetings between TRIUMF physicists and our LOoW research team we drafted the first Process Design comprised of four streams³ each with a series of different relays, all inspired by the use of Feynman's diagrams for calculating complex interactions.⁴ In January 2017 we organized a Science Seminar for artists and art students on a topic chosen by the physicists for artistic responses. The physicists had decided on a major topic in current physics research. They presented antimatter in various formats from a lecture to demonstrations and interactive components, ensuring that the abstract concept was activated through multiple forms - the standard lecture, a live interview with CERN experimentalists, visuals, diagrammatics, analogies, and even performance. Over the next eight months, through the field of co-thought, artists took up the unimaginable topic of antimatter.

³ Twenty-six curated artists were partnered with twenty-six physicists to collaborate in a process of relays through a Blind Stream, Dialogical Stream, Tandem Stream, and a Fieldwork Stream (with students in an experimental art class)

⁴ Theoretical physicist Richard Feynman developed visual representations of mathematical expressions that show particle paths in quantum field theory.



LOoW Process Design - drawing by Ingrid Koenig (2017)

One of the great mysteries of modern physics is why antimatter didn't destroy the universe at the beginning of time. Besides this query, other aspects of antimatter that provoked inspiration for the artists include: it has a reversed electrical charge to matter; it opens up the possibility for time reversal; upon contact, matter and antimatter annihilate one another, leaving behind other subatomic particles—this annihilation process results in an explosion that emits pure radiation traveling at the speed of light; once produced antimatter can be trapped and stored, albeit with difficulty. During this seminar the interactive activities, though often overwhelming for the artists, also helped us to understand the infinitesimally small amount of antimatter that currently exists in the universe.

The apprehension of complex phenomena fuels our attempts to understand the world and to develop a language to explain the universe between and among diverse approaches to knowledge formation. By *Leaning Out of Windows* we had stepped out of our familiar mind-set and co-designed with the physicists a deterritorialized structure for co-thinking. The search for antimatter is complex and the concept not easily grasped, especially as it exists in theory and through mathematical principles, but also in unfathomable fusion processes within the sun. These phenomena along with mutual annihilations, processes of negation, and time reversal are alien to human cognition beyond the science lab. Yet the results of co-thought revealed a way to navigate the unknown and the unrepresentable. The creative process enabled the subconscious, encouraged wandering, allowed for contextualizing with our socio-political lives, emboldened conversing across languages and temporalities, even allowing misapprehension, all with the aim to approach thinking in a different way, while troubling the mind with antimatter.

In January 2018 the exhibition *Leaning out of Windows, Step One* opened at Emily Carr University's new campus, showcasing the artworks from the first design process of relays and interactions between artists, art students, and physicists. Media included painting, sculpture,

print, installation, photography, collage, drawing, video, VR, sound composition, dance and writing. While some ideas were lost or dropped in the relay of artists, others persevered, creating provocative aesthetic responses to the science topic. In the exhibit, works were installed in clusters that reflected the sequence of interactions between artists, including visual and textual responses from their assigned physicists. The vast range of works attested to physicist Lisa Randall's statement: "You might say we are all searching for the language of the universe" (WP 2005, 73).

After the exhibition we sifted through the production streams and resulting feedback loops. When we mapped the emerging bigger picture in response to the topic of antimatter, we found that the world came rushing in. The physics concept of antimatter introduced ideas of resolution, sampling, decay and time reversal. But networked thinking also emerged connecting to the socio-political world, to philosophies, human experience, materiality, languages across time and across nature.

The following descriptions of a few works in the exhibition underscore common themes. Struggling to understand physicist Paul Dirac's development of an equation in 1929 that predicted the existence of antimatter, artist Elizabeth McKenzie produced a series of repetitive drawings in order to consider a cryptic proposal of something unfamiliar in a familiar way. Dirac's arcane formula dissolved and was reconfigured within this handling. McKenzie explained that her material investigation involving the repetition of an action allowed a familiarity to develop and this helped her see what she was thinking. Interestingly, when we showed this work to the physicists, they exclaimed that in their process of working they also utilize a great amount of repetition to familiarize themselves with difficult ideas.



Elizabeth McKenzie - *Equation*, ink on paper, 1 of 9 drawings (2017)

The question of embodiment and the relevance of human experience, both literally and as metaphor, also became a common theme. Related to these ideas was a complex work by performance artist Evann Siebens. In her aesthetic transformation of the previous works in her

relay, Siebens used dance, movement and juxtaposition of colour with black and white film to visually stand in for the oscillating dance between matter and antimatter. In her film loop titled *Time Reversal Symmetry*⁵ she played with the concepts of both charge-parity and time reversal symmetries⁶, as seen by mirroring and asymmetry. She was also interested in the multiple connotations behind the term 'time-reversal' and what that means for the aging technology of 16mm film, as well as the aging female body.



Evann Siebens - *Time Reversal Symmetry*, 16mm film loop - colour + B&W, 8 minutes (2017)

Another theme that moved through various works embraced what political theorist Jane Bennett calls the “vital materiality” (VB 2010, 10) that inhabits all things. This was especially evident in the relay comprised of work by Giorgio Magnanensi, Marina Roy and Mimi Gellman. Magnanensi’s *Sound Crystals/-H*⁷ was situated on the floor, consisting of maple and cedar wood audio resonators, and sound equipment to produce a microsonic environment. Magnanensi maintained an approach that, while mainly focusing on sonic imagination, explored the possibility of dialogue, relation and transference between visceral and intellectual knowledge. He also observed the process of consciously activating poetic and symbolic analogies while considering the chirps generated from synthesizing antihydrogen, and their vibrations of plasma clouds. There is an oscillation between antihydrogen and his apprehension of the traces of its possible, revealed, yet impenetrable existence, all resonating from these thinly-cut wood speakers.

⁵ <https://vimeo.com/243407473> - *Time Reversal Symmetry*

⁶ For further explanation of these concepts see <http://hyperphysics.phy-astr.gsu.edu/hbase/Particles/cpt.html>

⁷ <https://vimeo.com/268131107>

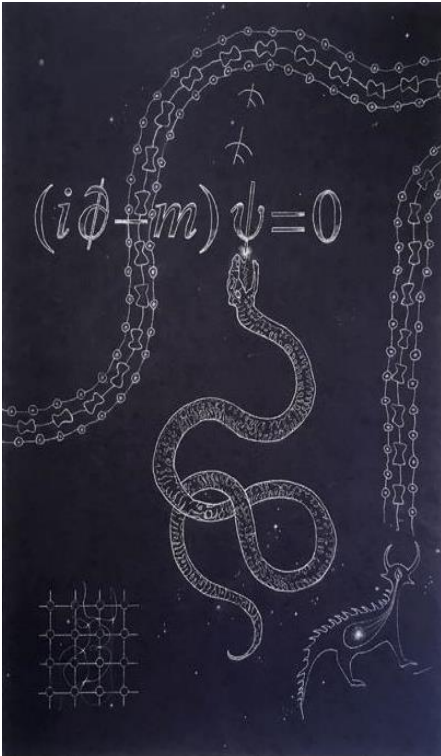


Marina Roy - *Dirty Clouds*, shellac, oil and acrylic paint on wood panel (2017)

Giorgio Magnanensi - *Sound Crystals /-H*, microsonic environment for variable sound clouds + maple, cedar flat audio resonators (2017)

The next artist in this relay, Marina Roy, began her process by responding to the material of wood in Magnanensi's work. With *Dirty Clouds* she produced eighty paintings made on wood panels. Roy was interested in reorganizing scientific ideas to aesthetically think through how material continues to disperse and flow. She did this through the matter of paint, mixing oil-based into water-based materials to symbolize a world understood according to material particles and waves of energy. Driven by unconscious and free association she made the analogy between antimatter and alchemy, bringing centuries old human history into what is now considered a more exact science, which does its best to do away with esoteric mysteries. Relatedly, in his book on antimatter, physicist Frank Close considers the formation of elements that we are made of. He writes: "So we are all stardust or, if you are less romantic, nuclear waste, for stars are nuclear furnaces with hydrogen as their primary fuel, starlight their energy output and assorted elements their 'ash' or waste products" (AM 2009, 16).

Mimi Gellman, the third artist in this relay received and responded to the works of both Magnanensi and Roy. The imagery in Roy and Gellman's work encompassed visual vocabulary from across histories. Gellman's drawings, *Invisible Landscapes* are blueprints of archetypal images from what she calls a collective unconscious. These diagrams gather dialogic memories and scientific data with Ojibwe patterns and symbols of Ojibwe entities to form new narratives. They reflect a coming together of seemingly disparate worldviews that in effect, Gellman says, are mere manifestations of different dialects. In this sense, she described her drawings as "exploring the architecture of consciousness".



Mimi Gellman - *Invisible Landscapes*, 1 of 6 conte drawings on Japanese Obonai paper (2017)

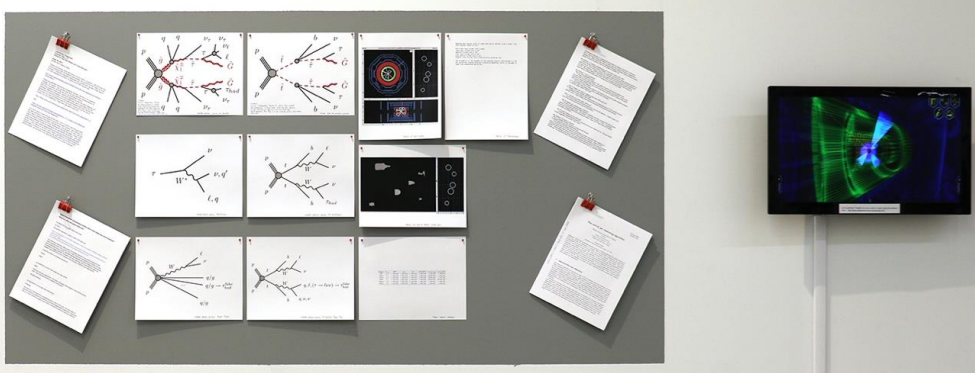
Socio-political connections emerged through a relay called the 'Blind Stream' where only the first artist, Heather Kai Smith, knew the science topic. For her drawings *Destruction Proves its Existence* she utilized a strategy of working associatively, using analogy and metaphor to explore specific forms such as the crowd, the mass, the party, the event. These forms were raised out of her interest in women's gatherings, protests, collective organizing, and resistance. Thus, her notion of a positron amplified the world connection to a force of resistance in current movements for social justice. This suggestion was "blindly" picked up by Maggie Groat's collages, the second artist in this Blind Stream relay, and furthered by the sound work of third artist, Andrea Young. In the fourth artist in this stream, Robert Bean's series of photographs, *Air Conditioning*, reflect on a term developed by philosopher Peter Sloterdijk to explain how the atmosphere as an environment was made explicit by the implementation of gas warfare in World War One. While picking up on socio-political references, the topic of antimatter was excavated unknowingly and placed into a different context that made a world connection to forces with profound negative impact.



Heather Kai Smith - *Destruction Proves its Existence*, 1 of 3 charcoal

Robert Bean - *Air Conditioning*, 1 of 3 inkjet prints (2017) + oil-based pencil drawings (2017)

Excluding the Blind Stream, communications and feedback loops with physicists were a key part of the production process. Scientists were asked to offer their specific interaction (a diagram, a drawing, an equation, a story, a metaphor, a short paper, etc.). These responses were included in the exhibition, and one that highlights this was the work of physicist Ewan Hill. His own research work involves experiments with antimatter at CERN's ATLAS detector. He asked himself - "how can I do my physics differently?" Hill converted the work of his assigned artist Natalie Purschwitz into physics objects as if recording a physics event. Hill thus interpreted her art as a plot of emerging new particles, as if coming from a physics process that ATLAS would like to discover and he designed a physics analysis to look for these new particles.



Physicist Ewan Hill - *Natalie Art Event Display* - response to Purschwitz artwork (2017)

During the exhibit we held a *Translation Hub*, inviting four scholars⁸ from neuroscience, music theory, physics, and art history, to discuss what emerged for them in the whole fabric of artworks. Artists, art students, and physicists participated in the conversation. One of many reflective outcomes on the collaborative approach to co-thought addressed how physicists and artists both changed the way they usually worked

⁸ Dr. Brian MacVicar, Co-Director of the Djavad Mowafaghian Centre for Brain Health, UBC; Dr. Ursula Brandstaetter, President of the Anton Bruckner Privatuniversität (for music, dance and theater), Linz, Austria; Dr. Timothy Meyer, Fermilab chief operating officer, Chicago; Dr. John O'Brian, art historian, writer, curator, UBC

within their respective fields. Fermilab physicist Tim Meyer spoke about the artworks helping scientists see how they themselves think, and that this collaboration brought more diverse ways of thinking about science. Questions have accumulated. We discovered the response to seemingly abstract knowledge through material matters had a tentacular quality, and we asked the question—where did the many leaps in thinking come from? While troubling the mind with antimatter, and by designing interactive conditions for co-thought between artists and scientists, we could see a path towards what feminist theorist Karen Barad calls a diffractive methodology where the spectrum of phenomena across “materiality, social practice, nature, and discourse must change to accommodate their mutual involvement” (MTUH 2007, 25). There was no full translation of antimatter, and never a “comprehensive grasp” in these cultural responses, but rather the engagement with antimatter required movement outside of one’s habitual way of thinking, and thereby we came to see the mind as a process.

A new phase of LooW was recently launched in September 2018, on the topic of Emergence. This next production phase of eleven teams, made up of artists, graduate art students, scientists and other scholars has been organized into collaborative groups as a way to test and further activate co-thought and associative thinking for comprehending complex phenomena. We speculate that new ways of thinking will arise from this process of co-thought. Rather than seeking integration, we are interested in the idea of holding different insights, different ways of knowing in relationship (IIS 2011, 67). We envision this as an evolving or emergent, multi-faceted phenomenon, encountered over time by holding in relationship different understandings of the science topic. The ways of knowing act on each other—in emergent ways that we cannot predict how—but that process is often fertile, if we pay attention.



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Comic Book Chemistry: Teaching Science Using Super Heroes

By Yann Brouillette



Every year, chemical breakthroughs captivate creative minds. Novel compounds are synthesized while new heroes are born. A great deal of science has inspired legends and multiple sagas have stimulated scientific curiosity. Together they have evolved as science fiction. I believe the science in fiction can be used to engage students. From the construction of Transformers to the Human Torch's fire and the Invisible Woman's

vanishing ability, key chemical concepts can be extracted from astonishing tales. The addition of arts to STEM curriculum via lectures, videos or class projects can foster student inquiry, dialogue and critical thinking.

Introduction

Marvel Comics is the biggest editor and publisher of monthly American comic books, featuring well-known characters such as Captain America, the Incredible Hulk, and the Invincible Iron Man. Since their acquisition by the Walt Disney Company in 2009, Marvel Studios also became the world leader in superhero blockbuster films. Superhero movies have grossed over a billion dollars worldwide in the last year, and the adaptation of comic book characters for TV shows have materialized exponentially, reaching out to a wide audience of scientific admirers, young and mature, as well as new science inquirers. Since shaping teaching like story-telling can make knowledge more memorable and meaningful (Judson, 2016), exploring superhero chemistry is an attention-grabbing angle for engaging students in science from K-12 through college.

For example, students often struggle to understand the concept of chemical bonding, which involves the linkage of atoms to form molecules. Using a Transformers analogy where six different small robots, the Constructicons, are needed to create one big robot, a Devastator, might simplify their grasping of the law of conservation of mass (Figure 1a). Students promptly get invested in solving the task and engage in manipulating in their heads the robots in disguise. Although the principle is the same, multiple small robots (or atoms) are needed to create a bigger robot (or molecule). While some learners can show initial resilience playing with abstract atoms, fewer resist these fictional icons. In a chemical reaction, the reactant that has the smallest stoichiometry amount in the reactant mixture limits the amount of product that can be formed. The limiting reagent is an important concept in stoichiometry that can also be illustrated by the Transformers' analogy. Even if eleven Constructicons are present, only one Devastator can be assembled (Figure 1b). If one of the six key Constructicons is missing, no Devastator can be put together, even if many instances of the other Constructicons are present.

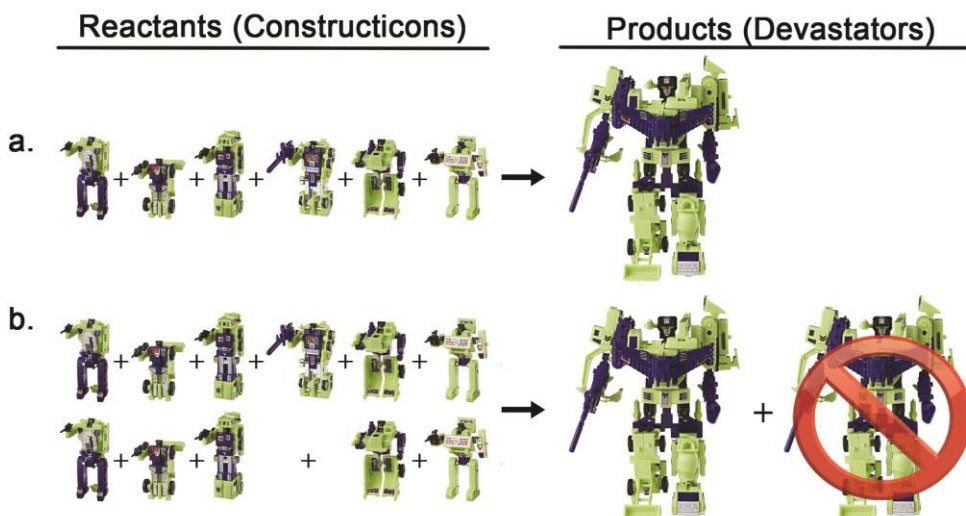


Figure 1. Using Transformers to illustrate the concept of chemical reaction, stoichiometry and limiting reagents. Six different Constructicons are needed as reagents to make one Devastator, the product.

Chemistry themes inspiring and inspired by fictional icons provide students with a relatable introduction to complex concepts. A fun and critical look at rational explanations describing out-of-the-ordinary events impersonated by characters seen in movies, TV shows and graphic novels triggers dynamic discussions as preambles as well as afterthoughts for learning. Superpowers, innovative armours, and marvellous abilities described in superhero universes offer a vast pool of cases that can be rationalized using chemical evidence. After all, everyone knows what truly makes a good story between heroes and villains... their chemistry!

Parallel universes in the same class

Around 420 BCE, pre-Socratic philosopher Empedocles stated that all matter was derived from four primordial substances—earth, fire, water and air. Although these “elements” have little resemblance to the modern sense of the term, this theory survived for the next two and half millennia until the inception of modern chemistry. Curiously, Empedocles’ views also influenced the creation of the first superhero team in 1961 by Marvel Comics: the Fantastic Four. Consciously or not, writer Stan Lee and illustrator Jack Kirby created a group of characters empowering the four elemental substances. The Thing was a bulky muscular man with orange rocks covering his skin, impersonating elemental earth. The Human Torch could engulf in flames at will to represent fire. Mister Fantastic mimicked water with the fluidity of his body that could stretch in any direction. The Invisible Woman could render herself indiscernible like air, which bears an interesting analogy with the discovery of X-rays by Wilhelm Conrad Röntgen. In 1901, he was awarded a Nobel Prize in physics for being the first man able to see through things.

Together, these versatile heroes were the building blocks of a whole fictional universe, much like the four classical elements were figurative concepts to explain matter in our universe. The same creative team behind the Fantastic Four must have realized how powerful elemental heroes were and gave rise years later to other chemically sound super heroes based on the periodic table of the elements, such as Iron Man (Fe, element 26), and the Silver Surfer (Ag, element 47) (Figure 2).

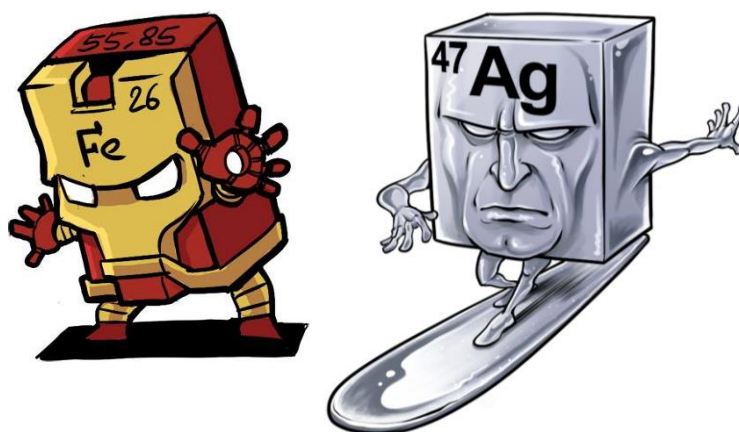


Figure 2. Iron Man and Silver Surfer, chemically sound super heroes created by writer Stan Lee and illustrator Jack Kirby for Marvel Comics.

Multiple parallels can be made between popular illustrated adventures and the advancement of science (Gresh & Weinberg, 2002, 2005; Kakalios, 2005; Fitzgerald, 2016; Lorch, 2017). The Canadian Neuroscience and Kinesiology professor E. Paul Zehr dedicated an entire book looking at brain-machine interfaces, physical limitations and technology necessary to create an armored robotic Iron Man suit (Zehr, 2011). In a recent publication, W. D. Lubell and I explain the hypothetical chemistry behind the transformation of the frail soldier Steve Rogers into the superhuman Captain America (Brouillette & Lubell, 2018). Get the article [here](http://goo.gl/aNG34b). (goo.gl/aNG34b)

Chemical engineering is now catching up to science fiction. Researchers recently created a polymer that can stretch to 100 times its original length, repair itself if punctured, and lead to artificial muscle (Kirby & Abate, 2016). This super stretchy self-healing material is not the work of Mister Fantastic, yet the analogy serves as an inspiring segue to introduce polymer Science.

To capture the colourful imagination of learners, lecturing about superheroes can be enhanced with visual support. Videos are a practical medium to convey information and engage a generation that has grown in the digital era.



Chem Curious: Pop Culture Laboratory Videos

The molecular makings of these superheroes merit examination through the eye of the test tube holder. At times, it may be impractical to bring student groups in the lab because of financial, logistic or safety reasons. Therefore, videos that represent chemical reactions reproducing special abilities of iconic characters in the laboratory allows synchronous and asynchronous viewing, teaching and discussion.

I have created an extensive series of short YouTube videos linking pop culture with chemical experiments over the last four years. These are freely available on the [Chem Curious channel](https://www.youtube.com/user/ChemCurious/videos) (<https://www.youtube.com/user/ChemCurious/videos>). Each video starts with a scene from a popular movie that is afterwards replicated in the lab, making it easy for any teacher to visually link the fiction and Science. In only a few minutes, entertainment can be educational.

Videos of multiple characters may be selected to match the teaching of basic chemistry concepts. For example, at the college level, students are asked to predict the outcome of redox reactions. While the electron transfer might be intangible for some, especially in the case of dissolved metals in solution, looking at ionic metals quickly precipitating out of an aqueous solution in the hands of a hero makes it more concrete. In [this](https://youtu.be/FsJoWSC70EO) video (<https://youtu.be/FsJoWSC70EO>), Colossus, the metal-coated skin hero, can be used to demonstrate how silver ions interact with copper. In a similar manner, videos on [Iceman's instant freezing touch](https://www.youtube.com/watch?v=-HgiPY5aKs4) (<https://www.youtube.com/watch?v=-HgiPY5aKs4>) or the [formation of a blue Jedi cavern](https://www.youtube.com/watch?v=o13LUWK6Uw0) can serve as examples of crystallization (<https://www.youtube.com/watch?v=o13LUWK6Uw0>). [The Green Goblin's pumpkin bombs](https://www.youtube.com/watch?v=uW2r0jGNp8I) (<https://www.youtube.com/watch?v=uW2r0jGNp8I>), producing acetylene gas from calcium carbide, is a complete scenario to study gas stoichiometry. Plasma can be safely brought to class via [this](https://www.youtube.com/watch?v=pors2NhLtQ0) video personifying Iron Man's energy source (<https://www.youtube.com/watch?v=pors2NhLtQ0>).

The more detailed examples below describe how seemingly extraordinary phenomenon can be feasible and explained using prior knowledge. (For the concise purpose of this article, the discussion on the lab-made videos will be limited to the chemistry behind specific features of the Fantastic Four.)

Sue Storm, better known as the Invisible Woman, probably has the power to give her body the same refractive index as her surroundings, hence letting light propagate through her without disruption, and creating the invisibility effect. This mirage can be reproduced in the lab by filling a pyrex beaker with glycerol (or glycerine). Since both materials have the same refractive index, the beaker will become imperceptible once dipped in glycerol.

Watch : [INVISIBLE WOMAN Refractive Index Invisibility \(https://goo.gl/LiYJ9f\)](https://goo.gl/LiYJ9f)



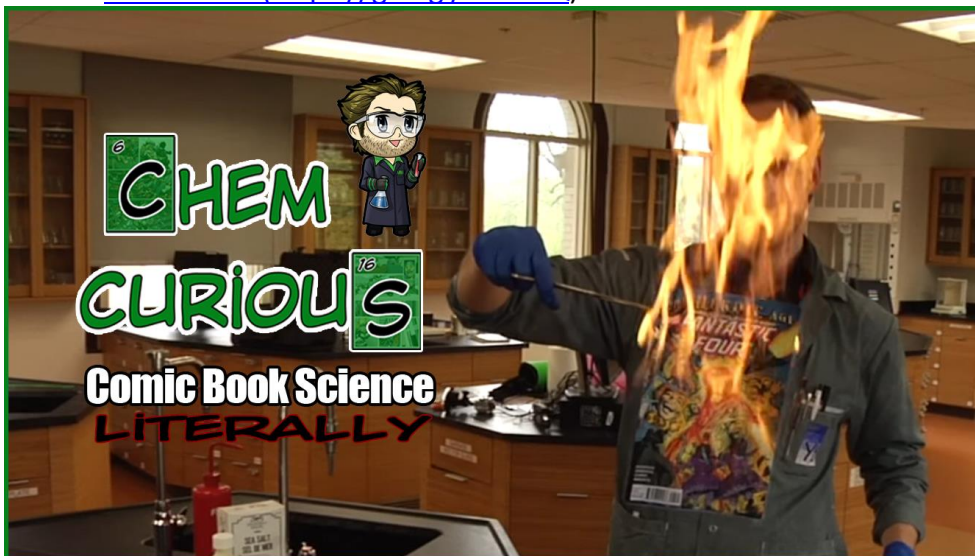
Another of Sue Storm's powers is to create invisible force fields. Making large soapy transparent spheres around figurines can be accomplished using liquid corn starch and/or glycerol in a watery soap bubble mixture. A bubble is made of three very thin layers of soap, water and soap. Since a bubble pops when the water that is trapped between the layers of soap evaporates, the glycerol or corn starch mixes with the soap to make it thicker. The thicker layer of soap prevents the quick evaporation of water, which allows the formation of bigger bubbles.

Watch : [INVISIBLE WOMAN Soap force field \(https://goo.gl/qzXp3S\)](https://goo.gl/qzXp3S)



The popular catch phrase "Flame on!" is shouted by the Human Torch every time he engulfs his body with flames. Once the fire dissipates, Johnny Storm, his alter-ego, has no burn scars. It is possible to get an actual comic book of the Human Torch to *flame on* (produce vivid orange flames) and then *flame off* (revealing pages that never caught on fire). The trick—or should we say the chemistry—involves using a 50:50 mixture of water and isopropyl alcohol (better known as rubbing alcohol), that we then light up. The alcohol will burn, but the presence of water, with its high specific heat capacity, absorbs the produced heat. Once all the ethanol is consumed, since it is the limiting reagent, no more flame will be formed. An intact comic book will be returned, albeit being wet.

Watch: **FLAME ON!** (<https://goo.gl/EvmckQ>)



A similar demonstration can be done using a comic book bag, which normally melts under a flame. But there is a way to preserve it, just like the Human Torch can preserve his costume. If the bag is filled with water ahead of time, the flame will not melt the plastic because the water absorbs the heat, unlike the plastic. The temperature of the water increases, but not enough to melt the bag. The black soot on the bag is due to impurities in the hydrocarbon used to fuel the burner.

Watch: [HUMAN TORCH Fireproof Comic Book Sleeve \(https://goo.gl/zNo9PF\)](https://goo.gl/zNo9PF)



By grouping comic book characters into teams, a teacher can combine chemical concepts. For example, at the end of the Fantastic Four movie (2005), the Human Torch and the Invisible Woman join efforts to create a fire tower to neutralize Doctor Doom. This sequence can be recreated to display combustion and oxidation. In the video below, using a mesh garbage can atop a turntable, alcohol was burnt in the presence of strontium chloride to generate a tall red flame when the system was rotating.

Watch: [FANTASTIC 4 Fire Tower \(https://goo.gl/s6Ejhz\)](https://goo.gl/s6Ejhz)



The pool of Chem Curious videos is constantly growing, with a dozen new videos added every year. The viewing of superpowers accessible in the laboratory motivates students to create their own fictional characters. The following class assignment engages students' imaginations and creativity as they research chemical facts.

Elemental Superhero Class Project

Elemental Superhero is a class project designed for non-science college students (17 to 20 years old) registered in a science-complementary course. It has been implemented successfully in five cohorts of 42 students and can be easily adapted to the K-12 science curriculum. The project's pedagogical framework fosters the use of students' prior knowledge by connecting chemical basic concepts with fictional superhero characters created during the activity. Furthermore, students peer-review their classmates' work to ultimately create an original chemically anchored artistic product.

The steps of this class project succinctly presented here are aimed at motivating students to document the potential applications and technological limits of various elements of the periodic table.

I divide the class into two groups. Each student chooses an element of the periodic table to create a fictional character that personifies the chosen atom. The first group creates superheroes while the second group design supervillains. Three descriptive properties of the elemental character must be given to highlight the character's appearance, behaviour and superpower (linked with the properties of the chosen element). Each student must draw their character (Figure 3).

For example, one student created "Sulfa Woman," a character with yellow curly hair due to the color of solid yellow sulfur and the S-S cross-links in the hair protein keratin. A loner, likely due to her pungent breath that exhales SO_2 , Sulfa Woman has elastic powers due to the plasticizing effects of liquid S_8 -sulfur (Tobolsky & Takahashi, 1964).

With the spirit of constructive criticism, every student is asked to add two properties to another student's elemental character. Analysis of their peers' findings has improved character design through feedback. Each student of the first group, the superheroes, is next required to pair-up with a student of the second group, the supervillains, to engage in a hero vs. villain confrontation. Each team is required to describe a "reactive encounter" between their two characters. For example, Sulfa Woman produced hydrogen sulfide to disable Dr Hydrogen in the preparation of his world-threatening H-bomb.

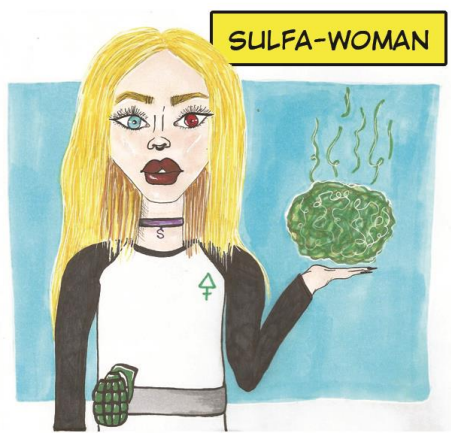


Figure 3. Elemental Superhero class project illustration by student.

Finally, each student pair is asked to produce a 1000-word essay depicting the adventures of the two characters using the chemistry of their respective elements. During the creative process, the instructor can ask students to complete a grid, that summarizes the important chemical items. The instructor's quick feedback on their grid reassures the students before the final version of the essay is written.

Important checkpoint items on the grid (that can be sent to you by email if you communicate with the author) include:

- Chemical Element
- Character Name and Alter-Ego
- Descriptive properties of the elemental character caused by the element.
- Appearance—the character's physical portrayal (body, face, hair, eyes, costume, equipment, etc.)
- Behaviour—personality traits
- Super power / Ability
- Descriptive reactivity of the elemental character caused by the element.
- A minimum of 3 different uses (outcomes, applications) of the element's properties (chemical reaction or change that will occur due to the ability of the character)
- Chemical encounter between hero and villain

Without any prior comic book knowledge, chemistry students have been engaged successfully in this pedagogic project that brings down boundaries between the arts and sciences to liven up discussion about elements and their reactivity.

Conclusion

A comic book narrative differentiates itself from other media by having plenty of its action taking place between panels, outside the box. Similarly, much chemistry takes place outside the lab. Chemistry is everywhere, and superhero prowess knows no boundaries. Comic books and chemistry can team-up to strengthen pedagogical approaches to learning via STEAM-based lectures, videos and class projects. After all, if knowledge is power, teachers can be superheroes.



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More STEAM Materials

<https://www.youtube.com/user/ChemCurious/videos>

<http://www.comicbookchemistry.com>

The ABCs of STEAM Culture: Establishing the Ground Rules for Risk-taking, Imagination, and Collaboration

By Brittany Harker Martin



As an arts integration specialist, the STEM vs STEAM debate has always been a bit of an enigma to me. In my career, all of the arts (art, dance, drama, and music) have been essential to teaching STEM because of their inherent power to represent complex holistic, visual, and relational concepts (Eisner, 2002a; Koester, 2015; Land, 2013; Lima & Timm-Bottos, 2018; Sousa & Pilecki, 2013). This is especially powerful for kinesthetic, spatial, and second/additional language learners, often marginalized by other teaching methods (Eisner, 2005; Gardner, 2011a; Noddings, 2005; Martin & Calvert, 2018; Rabkin & Redmond, 2006; Stein, 2000).

STEAM educators do not see the arts as subjects to be taught in addition to STEM (Ghanbari, 2015; Koester, 2017; Van Sickle & Koester, 2017). Instead, they see the arts as ways through which students can ponder, create, express, and represent ideas; like alternate languages beyond reading, writing, speaking, and listening (Eisner, 2002a; Martin, 2016). The arts enrich interdisciplinary learning and engage students in ways that traditional pedagogies do not (Gardner, 2011b; Eisner, 2002b; Martin & Calvert, 2018). To exclude the A from STEAM is to possibly exclude some students.

I often encounter STEM educators who are interested in integrating the arts, but lack the training and/or experience to effectively facilitate them. The purpose of this article is to help teachers who want to give STEAM a try. I articulate three ground rules for dramatic roleplay (what I call the ABC's) that each contributes to a STEAM Culture supportive of students taking intellectual risks, imagining, and collaborating together. I also provide sample exercises that help establish these ground rules as well as a variety of soft skills prized in the fields of science, technology, engineering and math.

Integrating Drama

Arts integration can be defined as the regular use of the arts as a tool for learning and representing knowledge within another subject (Martin, 2016; Rabkin & Redmond, 2006). For teachers interested in but inexperienced with the arts, my first suggestion is often dramatic roleplay because it is an empirically tested way to empower students and increase engagement through collective action, invited student input, and embedded student agency (Bandura, 2000; Martin & Calvert, 2018; Martin, *in press*).

Dramatic roleplay is a form of arts integration that has its roots in theatre games, originally played to enrich the actors' understanding of an imagined world. It has been embraced by educators who realize its pedagogical merit for inquiry and imaginative exploration of a learning context (Heathcote & Herbert, 1985; Neelands & Goode, 2000; Norris, 2009).

Classroom drama is not about putting on a performance. It is about the *experience* and *embodiment* of characters and concepts for a deeper, more personalized understanding of the context and content being studied. In roleplay, the acting is not scripted—it emerges live, as improvised scenes queued up by the teacher who is often also in role. Students then co-create the unfolding drama, to make decisions that influence the direction of the action in such a way that they are empowered and engaged (Martin, 2018). The resulting work looks like improvised episodes, packed with observable learner outcomes. For example, the teacher might call a meeting as the Minister of Intergalactic Relations (teacher in-role) leading a team of engineers (students in-role) to discuss a robotic challenge on Mars. Much of the discussion in role is similar to a typical STEM dialogue about robotics, but there is an added layer of fun and complexity that requires students to apply what they know, within the action.

One common pitfall for teachers who try drama, is the staging of a *skit*, with students acting in front of others without adequate preparation for the complexity and conventions of theatrical work. This can end in a number of negative ways from silly play devoid of meaning, or worse, to embarrassing students who don't know what to do. To avoid this, the right classroom culture needs to be created; one where students are trusting and willing to take risks together, imaginative and willing to engage in hypothetical scenarios, and collaborative and willing to work inclusively.

The ABC's of STEAM Culture

Facilitating live roleplay can be intimidating; yet, outside theatrical circles, a little known fact about improvisational roleplay is that it relies on specific structures that allow for facilitator control. In my experience, the following three ground rules reinforce these

structures: A) *All-in, for-All*; B) *Believing and Being*; and C) *Collective Contribution*. Establishing these ground rules creates a classroom culture ripe for STEAM-based activities.

All-in, for-All. For many students, acting can feel unnatural, even embarrassing when it is not facilitated properly. In a classroom culture that supports dramatic roleplay, participants need to trust each other and be willing to take risks together in a way that no one feels individually vulnerable. To achieve this, everyone must be *all-in*, and commit to pushing past personal discomfort for the benefit of *all*. An *All-in, for-All* expectation can be accomplished through adequate ice breaking that builds trust as a class. I like to use *The Questions Game* for its power to establish active, respectful participation as the norm.

Questions Game: Put students into groups of 4-6. Ask for two volunteers to *go first*, and be in the *hot seat* (the active players). The rest of the group members serve as audience-referees. The game is simple: players can only ask questions. They cannot answer a question, make a statement, or take more than 3-5 seconds to respond to the other player's question. The game begins with the first question, and they ask each other questions, in turn. The audience-referees call someone *out* when there is an answer, a statement, or time violation. When a player gets *out*, another group member takes the hot-seat, and the game resumes with his/her first question. Play the game for at least 15 minutes so everyone experiences the hot seat more than once. During play, try to spot groups that are holding back, and coach them to actively participate. Once everyone has had a turn, pause for a mid-point debrief to ask, "what do you think?" Typical responses are, "It's hard," or "It's hilarious." This debrief allows you to address how the very nature of the game is unnatural, and it only works if everyone is *All-in, for All*.

Through trust-building exercises like the *Questions Game*, you can establish *All-in, for-All*. Within a STEAM context, the benefits are that it establishes positive group norms where students are willing to be vulnerable and protective of that vulnerability. Creative problem solving requires a culture that promotes voicing novel ideas and learning from trial and error. Soft skills such as team work, comfort with risk and ambiguity, and interpersonal skills are a natural part of a STEM agenda, and *All-in, for-All* reinforces these.

Believing and Being. An important rule for roleplay is being able to *believe* that individuals are *being* someone else. In a classroom culture that supports dramatic roleplay, participants are imaginative and willing to engage in *what-if* scenarios. *Believing and Being* requires students to experience the perspectives of others, *as if* those perspectives are their own. Imagination is required as students are asked to empathize with, and relate to, other perspectives. One effective introduction to perspective taking is writing-in-role, as it helps individuals consider another perspective, without the added pressure of acting in front of others.

Writing-in-Role: Choose a writing format (diary, email, etc.) and put a starter sentence on the board (opening line to get started). Use a sentence that makes sense for the format, i.e., “Dear diary, today we had a meeting of intergalactic engineers.” Instruct students to use first person (*I, me, my*) and remind them that they are being asked to write *as if* they are their assigned characters. Beneath the starter sentence, write the following prompts: *I think ... I feel ... I hope ... I wonder....* These prompts help students get into character and really consider another point of view. Following the writing, volunteers may share and the class can discuss the differences between the characters’ opinions and the students’ own opinion (which can be very different), in a way that promotes metacognition.

Acting-in-Role: When students are ready to act in front of each other, they can turn products from writing-in-role into scripts to be performed, such as through readers’ theatre. At this point, they can benefit from side-coaching in a way that encourages them to *stay in role* through gentle reminders like, “*believe in what you are saying,*” and “*really be that character.*” The emphasis is on demonstrating belief in the drama, rather than on acting ability, through commitment to the role.

Through writing and acting in role, you can create a classroom culture rich with imagination. Within a STEAM context, the benefits are that it encourages and enhances creative and innovative thinking. Roleplay connects the logical, linear aspects of STEM to the inherent humanity, and often neglected: the empathetic, emotional, and ethical. Soft skills such as flexibility of mind, self-awareness, and ethical reasoning are a natural part of a STEM agenda, and *Believing and Being* reinforces these.

Collective Contribution: Developing characters and context together is measurably effective for student engagement (Martin & Calvert, 2018). In a classroom that supports dramatic roleplay, participants are collaborative and willing to work inclusively with everyone. The ground rule for *Collective Contribution* requires students to value the power of the group in a way that they balance generating their own ideas with actively listening to those of others. Collective ideation exercises, such as brainstorming together, encourage and signal a value for divergence of thought and diversity of voice. They are meant to engage everyone’s contribution and foster a classroom culture that perceives holistic benefits from the whole class.

Collective Ideation: Provide the group/class with a problem and open the floor for suggestions. Encourage everyone to make at least one, and if they are adding onto another, to begin with the phrase, “yes, and...” A simple phrase, this line helps participants learn how to *plus*, or build-on each other’s ideas. During idea gathering, discourage students from debating or ruling out the ideas of others (or even critiquing their own). Explain that there will be a time for narrowing ideas later, but that collective ideation involves gathering *all* ideas, since they may spark novel thoughts from

others. Once ideas are adequately gathered, it will be necessary to narrow the list and make decisions. This can be accomplished through democratic reduction.

Democratic Reduction: After a list of ideas is created, open the floor for discussion. Invite students to advocate for their preferred ideas (whether or not they originally suggested them). Discourage them from explaining what they do not like, or comparing ideas by positioning one against the other. Following discussion, take a vote, by raised hands or secret ballot. Teaching students to collectively converge on ideas through democratic reduction helps include everyone while establishing the norm of majority rules.

The ground rule of *Collective Contribution* honors every student's voice. Within a STEM context, the benefits are that it creates an environment where all ideas are valued while developing the skills required to converge on group-based, timely decisions. Soft skills such as active listening, openness to new ideas, divergent-convergent thinking, and critical-analytical thinking are a natural part of a STEM agenda, and *Collective Contribution* reinforces these.

Conclusion

By establishing the ABC's of STEAM Culture, teachers will feel better prepared for experimenting with roleplay in a way that prepares their class to take risks, imagine, and collaborate together. Through *All-in, for-All, Believing and Being, and Collective Contribution*, students are better prepared for STEAM-based activities, including roleplay. The exercises above are starting points for teachers to lead students through trust-building, working in role, and collective creation while they foster a wide variety of soft skills essential for STEAM. These include: team work, comfort with risk and ambiguity, interpersonal skills, flexibility of mind, self-awareness, ethical reasoning, active listening, openness to new ideas, divergent-convergent thinking; and critical-analytical thinking. Ultimately, through the ABC's of STEAM Culture teachers will prepare students for effective roleplay and set the stage for success.



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What Does Creativity Look Like in the STEAM Classroom?

By Elaine Perignat & Jen Katz-Buonincontro



Example of a classroom STEAM project.

Although a variety of models propose creativity as part of STEAM education (Allina, 2017; Daugherty, 2013; Partnership for 21st Century Skills, 2011), STEAM educators sometimes struggle with developing student creativity (Perignat & Katz-Buonincontro, 2018). As there are a variety of interpretations of creativity (Beghetto, Kaufman, & Baer, 2014), it can be difficult for teachers to decide how to foster creativity in STEAM classrooms (LaJevic, 2013; Liao, 2016). Researchers, too, struggle with how to observe complex constructs like creativity in the classroom (Gajda, Beghetto, & Karwowski, 2017). But classroom observations are vital for advancing educational research: They allow researchers to gain insight into the uniqueness of classrooms and the complexity of everyday life in schools (Yin, 2005), which can be hard to capture through other means of data collection.

This paper engages readers in a dialogue about what creativity looks like in a STEAM classroom. We present four creativity principles coupled with examples from preliminary qualitative observation data of a 5th grade STEAM classroom, and research tips on how to conduct quality classroom observations of creativity processes. The classroom has six STEAM instructors and 50 students in a private school located in Northeastern United States. Data was collected using a selective observation method (focused on specific activities) (Angrosino & Mays dePerez, 2000) and an observation protocol based on the Creativity Fostering Teacher Behaviors Index survey (CFTIndex) (Soh, 2000). Selective observations of teachers' actions, interactions, and responses that matched nine CFTIndex principle behavioral areas were recorded as written field notes during 12 STEAM classes, each lasting 60 minutes in duration. We define "creativity" and then discuss four of the nine CFTIndex principles most relevant to fostering creativity in STEAM classrooms.

Creativity

A common definition of creativity (creative idea, product, or behavior) combines novelty, utility, *and* quality (Kaufman & Sternberg, 2007; Kozbelt, Beghetto, & Runco, 2010). Fostering creativity in STEAM education is necessary for enhancing students' independent and flexible thinking, creative self-efficacy, and creative problem-solving skills. Research has shown that creativity is learned through example and practice (Root-Bernstein, 2015). Therefore, teachers are expected to model the values and behaviors of creativity while maintaining a supportive classroom atmosphere (Runco, 2014; Sternberg & Williams, 1996). Modeling creativity, allowing mistakes, and rewarding creative ideas are also important (Sternberg & Williams, 1996). Cropley (1995) believed that educators may find these suggestions too vague and therefore composed a practical list of nine principles for fostering creativity in the classroom, which formed the basis of the observation protocol used in this study. Here we discuss four of these nine creativity principles:

Principle 1: Motivate students to master factual knowledge, to build a solid base for divergent thinking.

Overview: Despite the misconception that creative ideas are developed from nothing, creativity requires a strong foundation of subject knowledge and skills (Baer & Garrett, 2010; Soh, 2017). Mastery of knowledge allows students to think flexibly or divergently by branching out from available information or seeing new insights that are unnoticed by others. In turn, this helps students come up with new ideas that are both appropriate and unique to the subject area (Cropley, 1995).

Classroom Example: An example of this principle was observed at several points during a study of six teachers in a 5th grade STEAM classroom. The STEAM unit teaches students about the effects of global warming, extreme weather, and their destruction of houses and communities. Students are expected to master understanding of global warming and extreme weather in order to design and build an effective hurricane-proof house prototype. As students progress through the unit, teachers give students opportunities to think critically about global warming and the impact of extreme

weather. For instance, Ms. Andrews asked students to relate a reading on water surges to their house designs by asking, “Based on your readings, how high can a storm surge go? And why are windows a huge consideration?” After open discussion, students added innovative design elements like wetsuits and rubber seals to protect their houses. By asking students to connect information from a reading assignment to their house designs, students were able to master factual knowledge about storm surges and then apply their knowledge to their housing designs (Perignat, 2018).

Research Tip: Expert knowledge is developed by offering a variety of opportunities for student reflection, engaging prior knowledge, and practicing inquiry and critical thinking in multiple contexts and task materials (Sawyer, 2015). In a STEAM classroom, researchers should avoid dependency on frequency counts of teacher behavior, which may not be indicators of teachers’ effective teaching (Forrester & Hui, 2007), but instead observe the range and quality of opportunities for student engagement through exploration, open-ended inquiry, self-expression, and authentic assessments for demonstrating students’ deeper conceptual understanding (Sawyer, 2015).

Principle 2: Delay judging students' ideas until they have been thoroughly worked out and clearly formulated.

Overview: When teachers delay judgement of students’ questions, ideas, and suggestions, it demonstrates to students that their creative ideas are supported and valued. This perceived teacher support is necessary for developing students’ creative self-efficacy, willingness to take intellectual risks, self-evaluation, and independent thinking (Beghetto, 2009; Soh, 2017). If students do not feel supported in this way, they will refrain from sharing ideas and instead only share ideas they think the teacher wants to hear (Beghetto, 2009).

Classroom Example: An example of this principle in the 5th grade STEAM class occurred during a one-day design challenge in which groups of students were asked to create an inventive prototype to solve an assigned problem using one bag of materials. Students designed an array of solutions using items like popsicle sticks, straws, cotton balls, tape, and paper cups. At the end of class, students presented their solutions. One teacher, Mr. Cellitti, facilitated the discussions and carefully delayed judgment as students explained their inventions. The first group explained that their invention was a solution to carrying a heavy object. Mr. Cellitti asked, “how will you get the heavy object on top of your item to carry it?” The students provided an answer, and without responding Mr. Cellitti then asked, “What will your item be made of? What materials will you use?” The students responded with ideas for strong materials to build the design. Finally, Mr. Cellitti asked the students, “Who will use this invention? And does it have a name?” After the students answered, Mr. Cellitti thanked them for sharing, praised their work and ideas, and asked the next group to present (Perignat, 2018).

Research Tip: Documentation can be used to capture art outcomes in STEAM classrooms. But photographs and videos can be used to document the creative process, not just the final outcomes of STEAM projects. Sketches and “maker” statements show how students are working out the ideas behind their projects, and can complement the

more typical documentation of creative products, such as the model of the houses designed in the classroom example above. Maker statements allow students to articulate the personal meaning of their work, which researchers have suggested helps to boost student efficacy in creative environments with diverse student populations (Guay, 2000; Petsch, 2000; Wielgosz & Molyneux, 2015).

Principle 3: Offer students opportunities to work with a wide variety of materials and under many different conditions.

Overview: Recent studies have shown that classrooms where students feel that they are encouraged to think of unique ideas, learn from their mistakes, and explore and play with new materials and resources, enhances creative development (Craft, Jeffrey, & Leibling, 2001; Runco, 2014). Additionally, opportunities to explore with materials and conditions can diversify student experiences and help them find creative outlets in a variety of subject areas (Soh, 2017).

Classroom Example: The observed STEAM classroom included a variety of conditions and materials for students throughout the semester. For example, the one-day design challenge assigned students to work collaboratively with limited craft supplies. Later students made individual dioramas depicting the greenhouse effect using art materials and repurposed supplies brought from home. Finally, student groups are completing a long-term project of designing, building, and testing a house prototype that can withstand hurricane conditions in a lab. This project requires students to use substantial materials like wood, clay, cardboard, rubber, adhesives and other art materials and skills to build their design (Perignat, 2018).

Research Tip: Researchers, too, use their senses when observing how teachers use art materials in STEAM settings. It's vital to observe how teachers and students interact with materials, such as the wetness of clay or olfactory aspects such as the smell of wood burning using a hacksaw in a STEAM engineering woodshop. This might include showing students how to use materials (Coulson & Burke, 2013; James, 1997), how to interpret art (Budge, 2016) and make connections to real-world scenarios (Chiu, 2009). Another important aspect in classroom observations of STEAM creativity is to discern whether the *student* initiates activities, or whether the *teacher* initiates them (Robson & Rowe, 2012) as well as describing the quality of interactions between students and teachers (Biasutti, 2017; Budge, 2016). Maps can give a sense of classroom interactions (Donovan, Green, & Mason, 2014) and show how teachers move around the desks (cf. White, 1987 in Yin, 2005) to motivate student creativity.

Principle 4: Help students to learn to cope with frustration and failure, so that they have the courage to try the new and unusual.

Overview: Frustration and failure are essential elements of creative problem-solving, design processes, artistic processes, and other processes in which failure is a means for improvement (Petroski, 2001). However, students often perceive failure as a flaw and lose confidence or interest in learning. In order to encourage student perseverance, teachers need to model coping behaviors and incorporate failure into learning experiences.

Classroom Example: On the first day of the STEAM class in which Mr. Norman, one of the teachers, said to students, “Sometimes when things don’t go the way you expect, sometimes that means you...what? It’s a bad school word. [students respond]. Yes. You Fail. But failure here is good.” As students progressed through various design challenges and dioramas, the STEAM teachers encouraged perseverance by saying, “Well, if your first attempt didn’t work, what else can you do [to fix it]?” or “Yes. If you move one piece around, you may need to consider moving other pieces too. But test it out. See how it works.” Finally, the culminating hurricane-proof house design project incorporates purposeful failure. As students test their prototypes, failure is inevitable, and students are expected to reexamine their design, material choices, and make improvements (Perignat, 2018).

Research Tip: When examining how students tackle problems and grapple with mistakes, it’s important to consider discrete as well as aggregated instances of teaching and learning creativity. This means examining students over time to see how they react to certain STEAM projects and instruction. Thus, it might be important to observe more than just one instance or episode of particularly rich classroom interaction between a student and a teacher (Katz-Buonincontro & Anderson, 2018). Because mistakes can be highly personal, observations should be fair in representing the students’ efforts, and give a sense of authenticity of the situation.

Conclusion

Taken together, these four creativity principles coupled with classroom examples and research tips give educators a sense of how to balance the constructs of educational rules, and regulations (Sternberg, 2015; Sternberg & Kaufman, 2018) with trying out new teaching ideas to enhance creativity in the STEAM classroom. Teachers should also be aware of factors that inhibit creativity in their classrooms. Factors like competition, restricted choices, pressure to conform, and rote learning can stifle creativity (de Souza Fleith, 2000). In order for teachers to support and foster creativity in their classrooms, they too must feel supported creatively by administrators and policy makers. Teachers should feel encouraged to develop new ideas, take initiative, interact with and learn from others, and take appropriate risks when developing STEAM curriculum. These actions will perpetuate positive creativity-fostering behaviors necessary for enhancing students’ creativity in STEAM.



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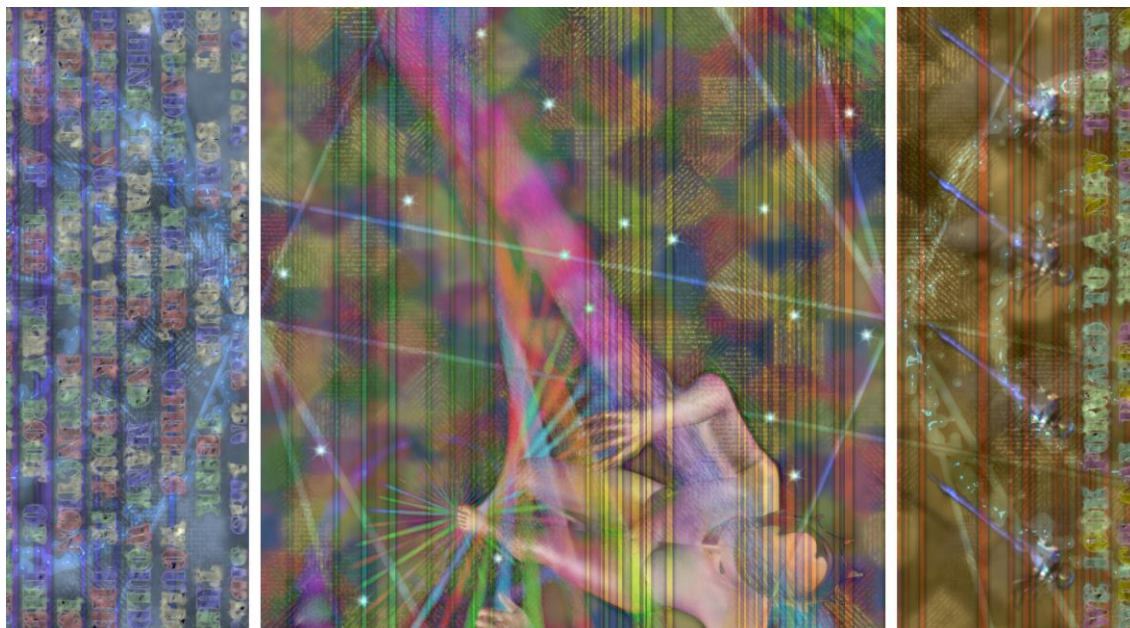
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Collage, Science and Art

By Dennis Summers



I studied both chemistry and fine art when I was in college, and most of my artwork since then has been inspired by science. It has also been influenced by my long-term interest in the mythic structures of non-EuroAmerican cultures, along with whatever other ideas I might find compelling at the time. Because of the wide range of not always obviously related topics, my work has generally taken the form of some sort of mixed or multi-media collage, as collage for me is the most suitable way to make engaging connections. For the first roughly 20 years of my career, most of my work was presented as multi-media site-specific sculptural installations. In the early years of this century, I recognized that the image quality of digital software had finally developed to the point that I could be satisfied with what could be crafted on computers and delivered as video. Most of my work since then has been synthetically created in compositing and 3D animation software.

I'd like to make a relevant digression regarding the development of my creative process over the decades. Early on, I would take scientific concepts, often from quantum physics, and consciously re-present them as modified aesthetic objects within ritualistic looking environments. Although I still believe that the work was effective, as time passed, I began to trust my intuition more. As years passed, I learned to create objects and use them in ways that just felt "right" to me. I would argue that my earlier approach was a by-product of the pedagogy of studio art classes, at least as practiced in the late 70s and early 80s, and I have no reason to think that it's changed. In such classes the student is always asked to justify their aesthetic decisions, and if they can't articulate a cogent defense their grades will suffer. I mention this because given the

context within which this article appears I believe that we need to be careful when assessing the quality of the “A” within STEAM. “A” requires different standards and approaches, and we should not lose sight of these distinctions when crafting both an educational environment and determining success.

As an example of my mature approach, and a potential model for others, I’m going to describe a long-term project that I’ve been working on for about 10 years called *Slow Light Shadow Matter* (SLSM). *Slow Light Shadow Matter* comprises 13 short digitally created animated videos—about four minutes each—twelve chapters and a prologue. It is presented on three screens, a center square panel and two vertical rectangular side panels. Taken together the image is at high definition (1920 x1080 pixels). This allows for an appropriate resolution of detail. The imagery in SLSM consists of complex motion collages, combining modified representational and non-representational elements, texts, music and voice. Most of the visual elements are synthetic—they are created entirely via software. The technical process is this: after doing the research, I determine which sorts of elements I’d like to include. Most of these are modeled and textured in 3D software. A smaller number of elements might originate as still images or video that are then considerably altered within the compositing software. Finally, all these elements are animated in different ways for each video chapter; animated texts are added, and it all is combined with different imaging effects processes, and audio elements added in order to create the final videos. The resulting piece is exceedingly dense with superimposed imagery, texts and audio. It may take viewers some time to parse out all of the components and their relationships.

What are some of these components? The title itself refers to two concepts from Physics. In 1999, scientists “used a new state of matter called a Bose-Einstein condensate ... to bring light down to the speed of a bicycle and then later to a dead halt” (Perkowitz, 2011, p. 8). This is called slow light. Shadow matter refers to a hypothetical substance “that interacts with ordinary matter, only by gravity, which means hardly at all” (Thomsen, 1985, p. 296). Each chapter draws from an artist-scientist dyad who were approximate contemporaries. I have yet to complete all the chapters and although the matching of individuals has been determined by intuition, over the years pairs have changed or specific people have been replaced.

The scientist/artist pairs as of this writing are listed here:

Prologue (El Greco)

1. Isaac Newton/Jan Vermeer
2. Michael Faraday/William Turner
3. James Clerk Maxwell/Claude Monet
4. Rosalind Franklin/Richard Long
5. Ernest Rutherford/Paul Cezanne
6. Niels Bohr/Wassily Kandinsky
7. David Bohm/Richard Pousette-Dart
8. Albert Hofmann/Pierre Soulages
9. John S. Bell/Jasper Johns
10. John Archibald Wheeler/Agnes Martin

11. Murray Gell-Mann/Sol Lewitt

12. James Lovelock or Lynn Margulis/Ana Mendieta

As mentioned, these pairings can't entirely be explained rationally, although I can give some indications. For example, I feel that the field theories developed by Faraday correspond to natural forces of fire, water etc. as painted by Turner. But this is where the power of collage comes into play. Even if I can't articulate the relationship, I can display it visually. Further on, I'll consider the John S. Bell/Jasper Johns chapter in more detail. But first I need to discuss some of the other elements that are included, along with some over-arching aesthetic strategies that I *can* articulate.

I investigate the physical nature and history of light (or more generally electromagnetism)—that of force and fields, and by extension, technologies of communication or information transfer. The scientists are almost all physicists who have worked with some aspect of electromagnetic or quantum theory. The work of the artists generally relates to light as color. There are three dissimilar scientists who represent a sub-theme of biology. Here too, divergent artists are included in order to develop other ideas. These three can be seen in the individual lines in the list above. Woven into the chapters is a cross-referential structure of systems that include alchemy, mythologies of non-EuroAmerican cultures, and Biology in order to draw out related conceptual connections.

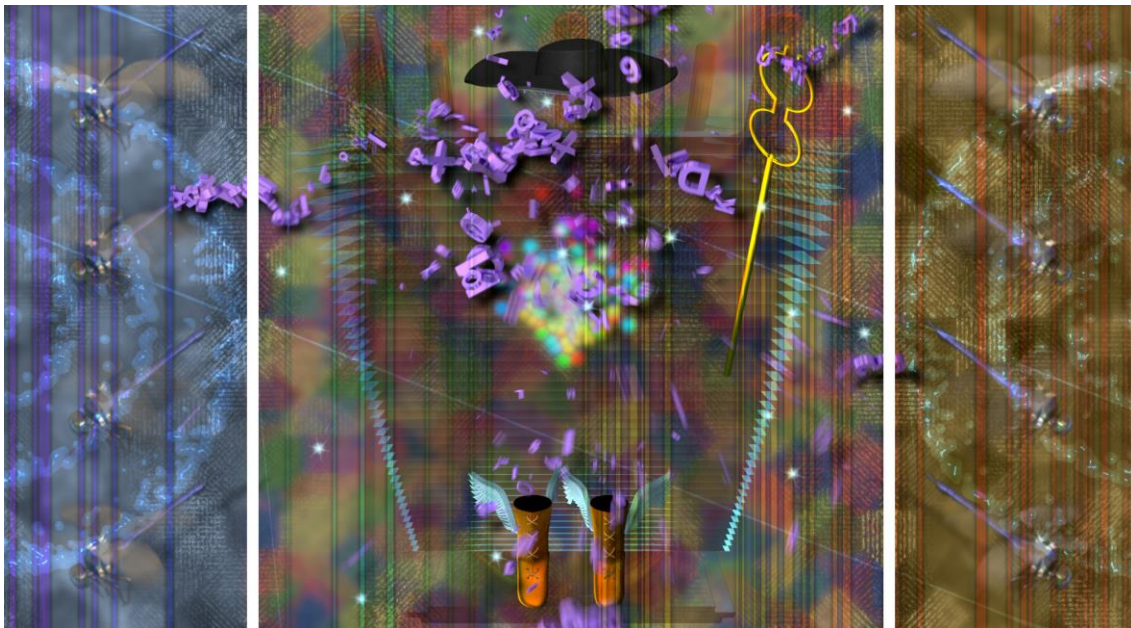
Although the scientists and artists differ from chapter to chapter, the entire series is bound together by multiple themes and motifs. For example, one "narrative" thread is based on stories and attributes of the Greek god Hermes. Hermes is displayed only by his iconic boots, hat and staff, along with a cluster of colorful, floating sparkly spots located at about his torso. Each chapter displays a different constellation of the zodiac, and a different pattern of emission spectra taken from the first 12 elements on the periodic chart.

So to be clear, although several components differ, there is a large group of elements that are reused in every chapter. As I've created each element in 3D software, I can animate them in different ways each time. So for example, in one chapter we may only see the object in extreme close-up moving horizontally across the screen; in a different chapter the element might start out small in the distance and then move toward the viewer with a corresponding increase in size until it moves past the camera and is gone. This ensures both visual and conceptual variety.

The point behind this variety comes from a construction methodology inspired by "modern" jazz music in general, and specifically the free-jazz of composer and saxophonist Ornette Coleman (interested readers should check out his album *In All Languages*). What I like about certain kinds of jazz is the way that the musicians will take a melody apart and reconstruct its elements with wide variety. Sometimes the same piece played on different occasions by the same band can sound unrecognizably different. In a nod to Coleman, I wrote a text that was recorded by voice-talent and mostly resembles his life and musical theory. I then split it into smaller sections that are incorporated into each video. Additionally, superimposed on the voice-over are free

improv compositions created by internationally known composer and musician Thollem Electric.

Let's now look at chapter 9 in detail. In all the still images reproduced here from the video, one can see that the background loosely resembles the series of paintings done by Jasper Johns largely from the 1970s known as the *crosshatch* paintings. (But unlike still paintings, the pattern in the video moves.) Many of the crosshatch paintings, some done on multiple panels locked together, create complicated mirrored structures of patterns. Sometimes these patterns "match" from one outside edge to the edge of the opposite side of the painting. For me, these sorts of patterns somehow speak to the work that made the physicist John S. Bell so important. Known as Bell's Theorem, and written in the 1960s, it was a relatively simple mathematical proof that showed that classical physics could not accurately account for a certain kind of quantum behavior, and by implication that quantum mechanics could. This proof suggested real experimental tests that could be performed to exhibit quantum entanglement. The experiments were designed with increasing accuracy over subsequent decades. Quantum entanglement is a puzzling aspect of atomic particles. As described in the proof and created in physical tests, two linked particles could be shot out in opposite directions. Then at great distances a characteristic (technically known as *spin*) could be measured on one particle. Mysteriously, this measurement alone could seemingly determine the characteristic of the corresponding particle great distances away. These characteristics could loosely be described as mirror images. And it is this mirroring which to me resembles the patterns of Johns' paintings. Additionally, although I can't address it here in depth, the work of both men fits uncomfortably into that of their contemporaries.



In this frame one can see the figure of Hermes mentioned earlier in this article. Purple letters and numbers can be seen spiraling out of his "body". Hermes was recognized as the god who created language and numbers. In the way that collage structures can link

so well, Johns has created many paintings in which numbers and letters are either the subject or important components.



Another figure that is seen in each chapter from various perspectives is the alchemical hermaphrodite climbing a DNA double helix. It is seen in the center panel of frame 1071. Here is an example of trusting my intuition, as I'm not certain that I could actually articulate why I've included this component. In this image, one can also see the texts that move horizontally across the side panels. These texts are taken from the writings of Bell.



Each chapter also includes a different architectural structure that can range from monuments like Stonehenge to one of Apollo's Temples, as seen in frame 2550. There

are several stories in Greek mythology where the activities of Hermes and Apollo overlap in interesting ways. Additionally, Apollo was the god of light and the sun, which in this frame can also be seen by the representation of the Egyptian god Ra who carried the sun across the sky in a boat on the back of a snake.



One last component I'd like to point out is the mouse in the bottom corner of this frame. The original source is video—altered considerably—that shows a mouse whose behavior is controlled by light pulses running through a cable implanted into his brain. The reader will note that I haven't explained every element seen in these frames, nor others seen elsewhere within the complete video, but I think that I've exposed enough to show how the complex interrelated nature of collage can be a powerful tool for drawing together ideas from science, art, mythology and more. ([Here](#) is a link to the complete video.)



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The STS Futures Lab at James Madison University: Integrating Design Fiction, Experimental Pedagogy, and Anticipatory Research into STEM Education and Outreach

By Emily York, Shannon N. Conley and Samuel Kodua



How can we creatively engage STEM students in reflecting on what it means to be a responsible innovator? How can we make responsible innovation, ethical thinking, and problem-solving hands on, interesting, and relevant for our students? How can we encourage them to recognize and challenge their own assumptions about progress? These are questions that we, as faculty in the School of Integrated Sciences (SIS) at James Madison University in Harrisonburg, Virginia, are constantly grappling with. Our primary appointments are in the bachelor's degree program in Integrated Science and Technology (ISAT) within SIS, and our role, specifically, is to engage students in reflecting on the "social contexts" of technology and science. ISAT is a unique, interdisciplinary, ABET-accredited applied science and technology program that trains students to analyze and address complex sociotechnical problems with a systems-thinking mindset. Our holistic problem-solving curriculum builds on a broad foundation of fundamental

knowledge in the natural sciences, computing, and social sciences, and includes a "spine" set of courses that teach students how to integrate multiple kinds of expertise to address problems, and to integrate the social and technical aspects of problems and solutions. It is a key goal to make the social contexts portion of the curriculum well-integrated into students' applied science and technology coursework. The challenges of doing this are also opportunities to re-think our pedagogical approaches. For example, we established the STS Futures Lab to embrace *doing* social contexts as part of *doing* science and technology—an approach that leverages the lab setting and hands-on project-based coursework students were familiar with in their STEM classes and applies it to social contexts. The STS Futures Lab supports our endeavors in the classroom, provides opportunities for us and our colleagues and students to experiment and innovate, and further legitimizes the social contexts curriculum.

The STS Futures Lab

Envisioned as a space for research and teaching, the STS Futures Lab is a fun, interdisciplinary, and intellectually stimulating environment where faculty and students can explore tools and practices that help us to plausibly anticipate the social, ethical, and political dimensions of high tech innovation. Aimed at building our capacities for responding to and reasoning about the fast-paced and impactful changes that confront society through science and technology, we believe that we urgently need more robust methods for the democratic governance of emerging technologies. Learning how to identify and examine varied aspects of sociotechnical change will benefit STEM students, whether they expect to work in R&D, policy, education, or business.

Our work as advisors in the Autonomous Vehicle Capstone team in SIS lead us to regular summer meetings with two of our students in preparation for a fall conference presentation. As our students moved back and forth between the computer lab where they worked on prototyping a 1/8 scale autonomous vehicle and our meetings where we discussed readings and examined the ethical dimensions of autonomous vehicles, they began to refer to our meetings as the "STS lab"—that is, the Science, Technology, & Society Lab. We began to work with our students on incorporating two tools—scenario analysis and design fiction—to facilitate our thinking about the potential futures of autonomous vehicles. We found these tools to be extremely useful and thought provoking. Chase Collins, one of our students and now a recent alumnus who co-founded the STS Futures Lab with us, helped us to experiment with gamifying our scenario analysis, and he ultimately led a workshop with the rest of the Autonomous Vehicles Capstone team that became part of their capstone project. Building on this experience, we launched the STS Futures Lab with an associated small independent study course and an initial cohort of five ISAT student members meeting weekly to develop research, engage in STS dialogue, and form a supportive community. While not limited to scenario analysis and design fiction, these methodologies form the backbone of much of the futures-oriented work we do in the lab engaging anticipatory ethics and anticipatory governance.

What is scenario analysis?

Scenario analysis refers to a method primarily used in business consulting for analyzing plausible mid- to long-term scenarios relevant to a specific domain in order to anticipate and manage uncertainty. Scenario analysis facilitators lead groups through a series of steps, usually over the course of some months, to identify, analyze, and plan for plausible scenarios. Used in profit, non-profit, and governmental organizations, it has been widely recognized as a tool that helps leaders avoid the assumption that the future will be a steady, smooth continuation of the most obvious trends of today—an assumption that can lead to major failures! More recently, researchers in Science, Technology, and Society and Science and Technology Policy fields have begun to recognize the usefulness of this tool for technology governance. In the STS Futures Lab, we have adapted this method to suit different learning objectives and learning environments for applying critical thinking toward socio-technical change.

What is design fiction?

Design fiction refers to a practice that spans science, science fiction, and prototype design, to create media artifacts that help facilitate conversations about the social context within which a technology might be embedded. The most sophisticated examples of design fiction that we might frequently encounter come from Hollywood science-fiction films—scenes which show future technologies in the context of story, seamlessly challenging us to rethink what it means to be human in a future world in which the technologies shown are commonplace and ordinary. In the STS Futures Lab, we have adapted this practice to use a range of tools that we have access to—from traditional art supplies to digital media—to build on scenario analysis by creating an artifact that can be used to start a conversation and engage in ethical reasoning about a potential future in which our chosen high tech innovation is already ordinary. Shifting our gaze from the shiny tech object to the everyday context in which this object might live enables us to interrogate the social, ethical, and political dimensions of this technology beyond what we had originally anticipated. This “detour into the future” may even inform our contemporary design and policy choices. We are currently writing grants to support engagement with a variety of augmented reality and virtuality reality tools to expand the set of options for creating design fiction.

Adapting Scenario Analysis and Design Fiction In the Classroom

We have found that scenario analysis and design fiction is extremely flexible, and that it can be adapted to meet different learning objectives, course structures, and constraints. It is possible to do an abbreviated version in just one 75-minute class period that can still serve as a meaningful and engaging activity—particularly if students are already established in groups and have been working with one case study or research topic for some time prior to the activity.

However, with more time the scenario analysis and design fiction can be more deeply integrated into a module or research topic. In a course introducing students to science, technology, and society, we experimented with a multi-class engagement that

adapted the gamified version of the scenario analysis and design fiction activity developed by our student Chase Collins. Applied STEM students in Shannon Conley's sections participated in a multi-week interactive and hands-on case study focusing on the anticipatory governance and ethical implications of emerging autonomous vehicles (AV). Students were tasked with serving as consultants to a fictional state senator who required a briefing in multiple knowledge domains related to the technological, societal, and ethical aspects of the technology. Student groups were assigned different "knowledge domains" in which they were expected to conduct in-depth research and gain a robust working expertise within their particular domain. Prior to the students' final presentations, and equipped with the research from their knowledge domain, student teams participated in an adapted version of the gamified scenario analysis and design fiction activity, analysing issues related to AVs in regards to stakeholders, infrastructure, and social and ethical dimensions. Students had to create a 2D drawn representation of a "slice of life," imagining a world in which AVs were commonplace. The final design fictions varied based on the factors and stakeholder perspectives students received from the scenario analysis game. Following completion of the design fiction, students then had to analyze their 2D artwork using an ethical analysis framework. Students integrated their analysis and design fiction in their final briefing presentations to the fictional senator.

Similarly, students in Emily York's sections took the gamified scenario analysis and adapted it to their own case studies on a variety of topics and, over the course of two weeks, created design fictions that juxtaposed 2D and 3D elements to start a conversation about one of the plausible futures related to their case study. Using arts and craft materials, found objects, and digital media, they worked in groups to create multimodal design fictions. Then, in a poster-session style final exam session, they presented their design fictions to each of the other groups, engaging in dialogue about what made the future plausible or not, and finally applied ethical reasoning to examine their design fiction futures in individual reflections.

Adapting Scenario Analysis and Design Fiction for a Middle School STEM Engagement: An STS Future Lab Member's Perspective

These tools can also be adapted for a younger audience—and the process of adapting these tools is itself a great learning engagement for undergraduate students. Samuel Kodua is a third-year Integrated Science and Technology student at James Madison University focusing on sustainable energy and information and knowledge management and is a member of the STS Futures Lab. He is also the community service chair of an engineering/applied sciences fraternity at JMU.

One of their first community service projects was a collaboration with an after-school program and they were tasked with holding various STEM workshops that help students connect with STEM principles. As a member of the STS Futures Lab, Sam had been working on modifying the gamified scenario analysis/design fiction approach for different audiences. He focused on how these tools could be used to interpret burgeoning technologies through different situational contexts and stakeholder perspectives, and to approach philosophical inquiry into socio-technical change. Initially,

he modified the game process by stripping down the complexity of each step and choosing a technology that would be familiar to the students. He demoed this iteration in an STS Lab meeting, where Lab members served as participants and provided insights into the aspects of the activity that were especially engaging/interactive and criticisms about the parts that might not be applicable to middle school students. Sam took this feedback and further modified the game to reflect a “make your own comic book” approach, further simplifying the game design model and making it more interactive.

First, given 3 to 4 options, students set up a future world in which their technology is a commonplace innovation that is widely used throughout this future world. Then participants draw the fundamental design of the technology that would allow it to operate in the future world. Second, given another 3 to 4 options, students envision a scenario in which the technology can be particularly useful in solving a problem. Then the participants are tasked with designing the technology with attributes and features that make this scenario possible. Third, they pick a unique human perspective from a choice of 3 to 4 options, and add to the previous designs of the technology in a way that enables the user to apply it to solve the problem. Finally, students are given a comic book template to create a story about their future world in relation to their technology and scenario. This adaptation of the design fiction format is especially fun for younger students to creatively come up with inventive representations while developing an understanding of technology in society and responsible innovation.

Adapting Scenario Analysis and Design Fiction As A Research Methodology

We are also adapting our approaches and implementing them as a research methodology, in a scholarly project titled “Co-Imagining Futures with Scientists and Engineers.” We are using our techniques of collaborative imagination and infusing them into our ethnographic engagements with professional scientists and engineers in academia, industry, and government who are engaged in technology research and development. Thus, in addition to (and often as a part of) semi-structured interviews and observation, we work with our subjects to co-create scenario analyses and design fictions that interrogate potential futures that may emerge from their R&D work. Our goal is to not only disseminate our research collaborations via traditional outlets such as scholarly journals, but to also present these collaborations in more readily accessible and public engagement oriented contexts. We intend to create a podcast called “Weird Detours into the Future with Scientists and Engineers” and a YouTube channel recording our engagements using 360 VR video. Our hope is to establish a 2-way dialogue with members of the public, in which members of the public can collaboratively comment and experiment with us as we engage with scientists and engineers working at the bleeding edge of their disciplines.

Adapting Scenario Analysis and Design Fiction As a Public Engagement Strategy

Finally, our future plans include adapting our approaches for a community and civic engagement effort working with everyday citizens, scientific experts, and K-12 communities in reflecting on the roles and responsibilities of citizens and scientists

within a democracy. For example, enabling us to take our approach outside of the classroom and into our local community, we plan to invite citizens and scientists to participate in an “Imagining Harrisonburg” exercise in a forum such as the Harrisonburg Public Library where we collaboratively explore plausible socio-technical futures and responsible citizenship in light of emerging technologies related to topics such as autonomous vehicles and smart cities. Designed for all ages, we will have options ranging from traditional art materials to virtual reality and 3D printing prototyping for the design fiction activity. Citizen design fictions and student elaborations of the design fiction artifacts would then be displayed in public spaces in downtown Harrisonburg, and be highlighted on a First Friday event. Students members of our STS Futures Lab will work with us to design and facilitate this event.

How can I become involved?

Please contact us at yorker@jmu.edu or conleysn@jmu.edu, or alternatively, contact us using the contact form on [our website](https://sites.lib.jmu.edu/stsfutureslab/) (<https://sites.lib.jmu.edu/stsfutureslab/>) if:

- You are a technologist or researcher who would like to participate in our study, “Co-Imagining Futures.”
- You are interested in participating with us in the STS Futures Lab in a creative and fun way, and possibly becoming a lab affiliate.
- You would like templates and materials related to scenario analysis and design fiction to adapt for your own teaching and research purposes.
- You have other ideas for collaboration or engagement and would like to brainstorm exciting new possibilities!



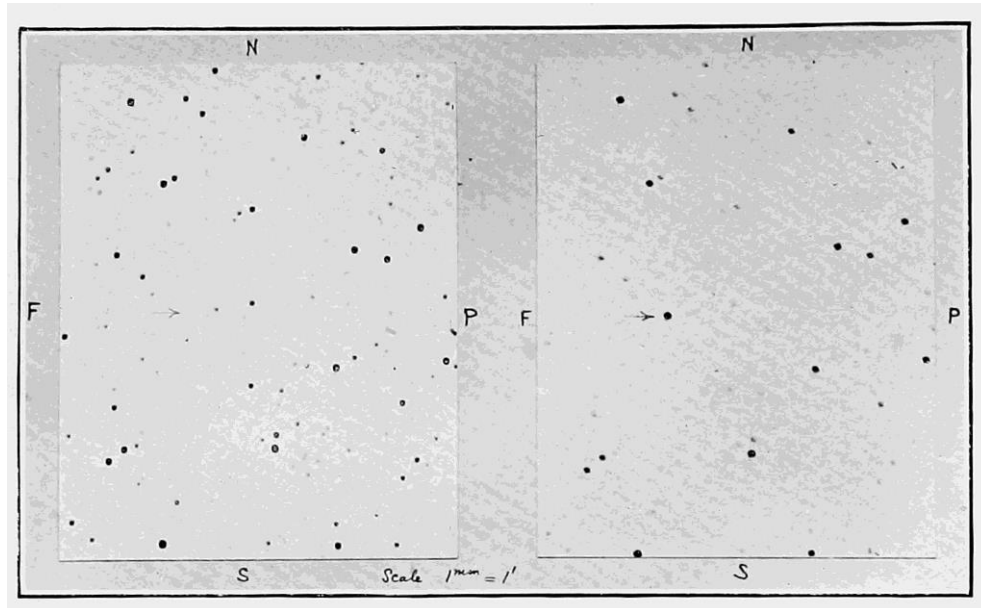
Shannon N. Conley is an assistant professor in Integrated Science and Technology at James Madison University and a co-founder of the JMU STS Futures Lab.

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Samuel Kodua is a third year in the Integrated Science and Technology program at James Madison University and a member of the JMU STS Futures Lab.

Experimenting with Writing/Writing with Experiments

By Pippa Goldschmidt



Astronomical Discovery; H.H. Turner (1904)¹

Imagine this:

You're in a lift. You're actually trapped in this lift and you can't see out, so you have no idea where you are. A single lightbulb illuminates the interior, the metal walls, the buttons you could (in theory) press. Except they don't seem to be working.

What do you feel?

You might feel a strange lurching sensation in your stomach, and alongside that a curious weightlessness. You might guess from this that you (and the lift) are in freefall, accelerating down towards the ground. Or you might equally guess that you (and the lift) are floating around in outer space, a long way from the Earth (and from any other planet or star or massive object), with no forces acting on you in any direction.

The truth is that it's impossible to distinguish between these two rather different scenarios. This person-in-a-box thought experiment was actually devised by Einstein in his development of general relativity (to demonstrate that gravity is not a particularly special force and can be transformed away). It's a typical one in that it uses an apparently straightforward (if rather extreme) situation to help illuminate some underlying physics.

¹ Retrieved from:

[https://commons.wikimedia.org/wiki/File:Astronomical_discovery_\(1904\)_ \(14593789467\).jpg](https://commons.wikimedia.org/wiki/File:Astronomical_discovery_(1904)_ (14593789467).jpg)

Einstein used a number of thought experiments in his work on relativity and quantum mechanics and they operate a bit like flash fictions, complete with a dependence on people and their experiences, and also upon the accoutrements of everyday life; trains, torches and lifts all populate Einstein's work. He wasn't the only twentieth-century physicist to use thought experiments to underpin his work, Schrödinger's cat is another example of an experiment that functions as a piece of fiction to generate some knowledge about the real world.

This is what fiction writers also know, fiction is 'made up' but it's influenced by the real and here's the thing—in turn it tells us something about the real. This boundary between real and not-real is porous, blurry.

Likewise, science attempts to grab hold of the material world but is often left holding nothing more than a set of equations, a database of numbers. A series of words.

But doesn't science require the same certainty as propaganda? Isn't the purpose of a scientific text to convince the reader that there is only one interpretation? That may be the case, but the reader is free to reject it. There's a difference between the ostensible aim of scientific writing, and its actual reception. In practice, other scientists read scientific accounts in order to test them, to pick holes, to find the gaps in logic, and the uncertainties in the data. These gaps are essential—out of these gaps spring the new work.

Put it another way; at what point does the following set of statements cross over from truth to fiction:

1. Imagine that you are trying to balance on the surface of an expanding balloon. List all the different ways in which this resembles reality.
2. Thousands of sub-atomic particles stream through you night and day. Does this account for those peculiar flashes of light you sometimes see?
3. You are trapped in a lift which is plummeting to the ground. Describe what you feel.
4. You are in a spaceship travelling towards a black hole. As you pass the event horizon and become cut off from the rest of the Universe, what do you observe?
5. What happens if you stop believing in gravity? Will you slide off the Earth?
6. What happens if you stop believing?²

I wrote this poem many years after I left school. I went to school in the 1980s in England, a time and place in which schoolkids were subject to a particularly narrow (and

² 'Physics for the unwary student', P. Goldschmidt, first published in 'Where Rockets Burn Through: contemporary science fiction poetry from the UK', 2012, Penned in the Margins, UK

in-depth) curriculum. From the age of fifteen I studied nothing but math, physics, and German, and when I asked if I could study something ‘arty’, such as art history, alongside all the hours and hours of calculus and geometry and mechanics and atomic theory and lab work and irregular verbs, the teachers laughed at me. You chose arts or sciences and that was that. I suppose I was lucky to be able to study German, and probably only that because it was thought to be a ‘scientific’ language.

Perhaps because of this, I have used my subsequent experiences as an academic scientist (I was an astrophysicist for a few years) as raw data for some rather unacademic practice—namely writing literature. Novels, short stories and poems. And I’m keen on helping other people to break down barriers between apparently unrelated subject matter.

Talking about thought experiments encourages people to see that making stuff up in their heads is not only interesting but also a story. It’s not only a story but also an aspect of scientific practice.

Workshop outline:

Show students a glass plate photograph of the night sky, taken at the UK Schmidt Telescope³ and commonly referred to by astronomers as a Schmidt plate.

Explain that this is actually a negative of the night sky, so that the objects are black and the sky itself is white.

Explain that every single black speck on this plate is either a star in our own galaxy, the Milky Way, or a more distant galaxy beyond the Milky Way. And you can tell the difference between stars and galaxies because the latter are fuzzier in appearance than the former and less likely to be circular. Tell them that we’re actually looking at these objects as they were in the past, because the light from them has taken so long to travel to us.

Tell the students that this sort of technology was developed in the nineteenth century and used until about twenty years ago.

Invite them to look at the photograph, and to pick it up and hold it up to a light source.

Now, ask them what emotions they feel when they look at, and hold, this object. For example, they might feel:

- Excitement and awe—wow! I’m looking at the Universe!
- Nostalgia—for old-fashioned technology dating from before the use of film.
- Insignificance—we’re so small and these objects are so big.
- Confusion—what does it all mean?
- Boredom—I don’t understand!
- Fear—are these objects looking at us in the way we’re looking at them?
- Connection—we can take photos of these things! We can understand them!

³ <https://www.aao.gov.au/about-us/uk-schmidt-telescope>

- Distance—they're unimaginably far away!

This is our way in to writing imaginatively about such objects, by considering and talking about the related emotions.

You can consider the gaps. There are always gaps in formal scientific narratives. The gap between what is described on the page and what actually happens in the lab when the experiment went wrong because someone spilt their coffee over the equipment, or someone tried to blow up the observatory. (A true story, the Royal Observatory in Edinburgh where I did my PhD and which used to house all the Schmidt plates was bombed by suffragettes in 1913).

Another gap comes in the guise of the ghost in the machine. That ghost is the author (or authors) of formal narratives who rarely refer to themselves as individual people with preferences, hang-ups or emotions. Writing fiction about the authors can help put flesh on that ghost, and reanimate them. And this is why we read novels. We know that what we're reading might not be historically true or factually correct, that even historical characters are essentially made up by the author in the way they construct speech and thoughts. But literature teaches us empathy and reveals psychological truths.

Apart from when I run workshops, much of my current writing is carried out in isolation. Just me and the intimidating blank screen, and a pile of books. But I am also an unofficial writer-in-residence at STIS, the Science, Technology and Innovation Studies unit in the School of Social Sciences at the University of Edinburgh. This means that I hang around at coffee time and ask questions about people's research, and from this rather caffeine-laden habit I have become involved in a number of creative interdisciplinary projects.

One of them relates to Freud's uncanny, the idea of the familiar gone strange, the thing that is not quite right and all the more eerie because of its relative closeness to the everyday. Our own bodies can be uncanny, they can attack themselves (through auto-immune disease), they can be augmented through implants and prosthetic limbs (which sometimes try too hard to be life-like), they can be kept alive by devices that are not themselves alive (autonomous heart defibrillators). So, a collection of social scientists and creative writers are working together to create uncanny fiction and non-fiction.

And when we ran a workshop on uncanny, one of the most fun things we did was to take Freud's essay and scribble all over it, and remake it. The familiar de-familiarised. This is often called 'found poetry', the workshop leader Nick-e Melville⁴ is an expert in this genre.

Each inter-disciplinary project that I am, or have been, involved in seems to require a different process so it can be hard to generalise about artistic practices and pedagogies. But, in general, when you're arranging for people from different disciplines to get together, a few basic rules are worth considering:

⁴ <http://www.scottishpoetrylibrary.org.uk/poet/nick-e-melville/>

Only get people together if they're genuinely enthusiastic. Everyone likes the sound of interdisciplinary projects but they take time to organise and are slow to get off the ground because people need time and space to learn about each other's work.

Don't make them a one-way street! Too many (far too many) projects assume that the scientists are there to instruct/enlighten/inform the artists, who will then dutifully go away and be 'inspired' by the scientists to produce something that illustrates their science. But scientists don't work in a vacuum (although they can literally work with vacuum, such as in particle accelerators)—see the beginning of this article. Experiments as fiction et cetera.

Paradoxically, to break down boundaries between people, it helps to acknowledge those boundaries. Make sure everyone knows about each person's expertise and interests in the lab or the studio before you give them fridge magnets to play with.

Not everything results in output. Sometimes it's a learning experience, a process. It may not produce anything tangible, or at least not yet.

Finally, try asking people what they find beautiful. Artists are used to this, but scientists can own beauty too and not just in the stars themselves, but in their representations on the page. There is an aesthetics to general relativity, when we talk about it, we refer to its elegance. This may be related to the ability to express truths concisely, and making few arbitrary assumptions about something material.

Enjoy the world, play with it and create new ones. And talk about them.



Pippa Goldschmidt is a writer based in Edinburgh, Scotland. She's the author of the novel *The Falling Sky* and the short story collection *The Need for Better Regulation of Outer Space*, as well as co-editor (with Tania Hershman) of *I Am Because You Are*, an anthology of short stories and essays celebrating the hundredth anniversary of general relativity (all originally published by Freight Books).

Stronger Together: Making STEAM Partnerships

By Karen McGarry

NOTE: This article (*Stronger Together: Making STEAM Partnerships*) has been rewritten from an Accepted Manuscript of an article published by Taylor & Francis in *Art Education* on 08 Feb 2018, available online: <http://www.tandfonline.com/>, <https://doi.org/10.1080/00043125.2018.1414535>.



Visualization of “Community of Learners” constructed as a maquette supporting lesson planning praxis.

Think of a stem. Perhaps you imagined a short shoot of green poking through a patch of dirt. Though fragile, a stem represents possibility, the potential for growth. Now think of steam. Typically, steam is imagined emanating from an engine or a teakettle: rising vapor created from a heated water phase change. One image, an outgrowth. Another, a product of an action. STEM and STEAM as acronyms for instructional praxis, consider the disciplines of science, technology, engineering, and mathematics, with the arts recognized as a partner for learning pathways in STEAM. The former president of the Rhode Island School of Design, John Maeda, once spoke about fostering critical thinking extended into critical making, or, in his words, “thinking as making” (Maeda, 2012). He stressed the historical connections between art and design and the STEM disciplines.

STEM initiatives date back to the 1950’s (Gonzales & Kuenzi, 2012), but Renaissance guild traditions occurred even earlier. Guild mentors transferred knowledge, skills, and dispositions to younger, untrained mentees in scientific, artistic, and craft/trade disciplines to secure the guilds and the institutions they promoted (Ito, as cited in Thompson, 2016, p. 53; Lucassen, De Moor, Luiten van Zanden, 2008; Prak, 2003, Rolling, 2016) as vital components in a learning, working ecology. Artists and scientists, working cooperatively, learned to question, to ponder, to reflect and to think, seeking answers and promoting question-based dialogic encounters. Guild-like learning between art and science disciplines have faded, though inquiry remains a vital

component for these disciplines. Arts-based learning may even promote literacy in Science when/if the two disciplines “re-connect” (Seifter as cited in Robelen, 2011, p. 2; Seifter, 2013). Connecting the disciplines of art and design may contribute to innovation and discovery and embrace the “A” as an active participant in creative learning ecologies.

Advocating for or becoming agents of the “A” might illuminate relevant actionable pathways for transdisciplinary learning. Encouraging partnerships between STEM disciplines and the arts may illustrate one such pathway. Maeda’s STEM to STEAM initiatives suggest a path inclusive of the arts, recognizing how the arts enable learning based on active engagement in critical thinking or “thinking which is focused on the evaluation of various alternatives” (Lampert, 2006, p. 46). STEAM offers such an alternative.

To imagine agency through STEAM engagement, this article utilizes the *Voltron* metaphor to highlight how each letter in the STEAM acronym has individual significance, yet the potential to make deeper, meaningful impacts when used collectively. *Voltron*, a popular science-fiction animation, is a character comprised of individually color-coded robotic lions united as a force against evil. Building from this cooperative metaphor, I share examples of classroom partnership practice to illustrate meaningful STEAM integration education. To summarize, ideas for how educators might become agents of STEAM instruction are offered. My aim is to shift the paradigm of curriculum planning away from siloed learning and toward integrated, transdisciplinary education through STEAM learning ecologies.

Invoking the *Voltron* Metaphor

To illustrate the individual aspects of the STEAM acronym, the features of the *Voltron* character are invoked to metaphorically represent the disciplines of science, technology, engineering, arts, and mathematics as a STEAM design. Using a popular animated character to illustrate learning through STEAM praxis may also resonate with K-12 learners. My metaphor visually links one *Voltron* Lion with each letter in STEAM, suggesting an integrated, team-like coming together of the STEAM disciplines.

S (science) = the Green Lion: Guardian Spirit of the Forest



Curiosity is a trait of the Green Lion and similarly, scientific exploration is ripe with curiosity. When partnered with the arts, these two disciplines can co-mingle by visualizing scientific data, pondering uncharted planets, even potentially revealing an alternative presentation of scientific information.

Figure 1. Green Lion
by Katie Noble (2018).

T (technology) = the Red Lion: Guardian Spirit of the Core

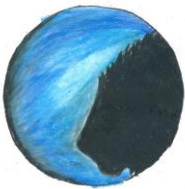
Speed and agility are two of the Red Lion traits, though much like technology, Red also has an erratic disposition. Partnered with the arts, technology supports creative tool application, revealing how art and design may positively impact innovations created through technological means (Fournier, 2013).

Figure 2. Red Lion
by Katie Noble (2018).

E (engineering) = the Yellow Lion: Guardian Spirit of the Land

The Yellow Lion is reliable, rough, and robust. To design and create, or engineer, takes “critical thinking dispositions” (Lampert, 2006, p. 215), or a disposition toward a commitment to problem solving through investigative means, planning, and a desire to innovate solid deliverables.

Figure 3. Yellow Lion
by Katie Noble (2018).

A (art & design) = the Blue Lion: Guardian Spirit of the Water

Like art and design, the Blue Lion carries traits of exploration and daring. The arts are welcoming of a multitude of expressive voices, techniques, and divergent thinking. Engaging in arts-based learning, expands awareness of alternative viewpoints and creates a more open, tolerant approach toward discovery education.

Figure 4. Blue lion
by Katie Noble (2018).

M (mathematics) = the Black Lion: Guardian Spirit of the Cosmos

The Black Lion is said to be a controlling force that unites the lions, though often challenging to maneuver. Mathematics unifies the other disciplines since math is present in the nuances within each strand. It is often described in artistic terms as being beautiful or having an aesthetic. Like the Black Lion calling *Voltron* to form, math can unite, bind and support the other letters in making a STEAM curriculum stronger together.

Figure 5. Black lion by
Katie Noble (2018).

Watch [this clip](https://youtu.be/MtqKaUc6Uas) from *Voltron*. (<https://youtu.be/MtqKaUc6Uas>)

The *Voltron* example illustrates a stronger together STEAM learning model that may foster a relevant student-centered learning ecology. K-12 schools that incorporate Project Based Learning (PBL) often use the art classroom as a pre-Engineering, thinking environment and utilize Engineering processes to design and innovate within a PBL curriculum. Art classrooms facilitating studio-based thinking/making/tinkering³, enable students through discovery and explorative practice.

Partnership Examples in Practice

The following are two examples of how I used a STEAM-focused curriculum model to impact teaching and learning in distinct learning environments: (1) a partnership between a high school art teacher and myself as co-constructors of PBL, and (2) a partnered practicum experience between pre-service and in-service elementary school teachers (McGarry, 2018).

Contemplate, Create, Innovate: Co-Constructing a PBL Experience

In 2013, I piloted a curriculum model titled, *Contemplate, Create, Innovate* with a visual arts teacher at a STEM high school in Hollywood, California⁴. Our PBL unit was titled, “Amuse Me.” We asked students to explore the question: *What can we create (an object, machine, toy) that is amusing?* Working in groups or individually, students designed prototypes responding to the essential question. To scaffold learning, students practiced creating gear boxes (Fig.6) and pop-ups (Fig.7) out of paper. We introduced Rube Goldberg machines to illustrate motion and students deconstructed toys to understand technical mechanisms within any moving parts. As in engineering practices, students kept regular logs to record task completion and feedback sessions with peers. Once the prototypes were complete, students presented their investigative responses to their peers.

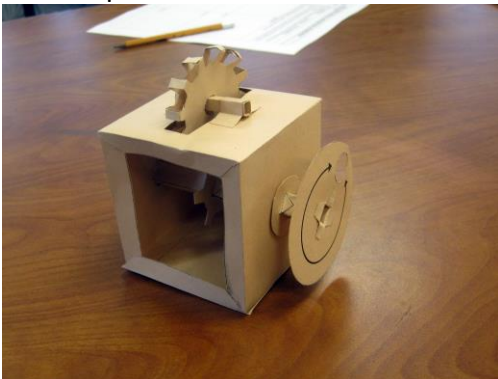


Figure 6. Paper gear box construction



Figure 7. Paper pop-up construction

The “A,” in partnership with other disciplines, asks students to think differently, imaginatively, and without the restraints of finding a right answer. An art lesson may ask students to create something, apply certain skills, and meet certain assessment criteria. The arts ask us to question, to develop our own questions based on what we see, hear, feel. Questioning often leads to more questioning (Berger, 2014), more contemplation, creation, and possibly innovation. Questions channel discovery and experimentation or extend inquiry, but regardless of the outcome, transdisciplinary learning has the potential to unleash experiences and propel STEAM practices in learning ecologies.

Pre-Service Practicum Partnerships

While teaching at California State University Long Beach (CSULB), I developed a partnership between my pre-service teachers and teachers at a local elementary school. Our partnership consisted of a cohort of pre-service teachers developing a unit of inquiry with authentic arts-based practices that integrated with specific K-5 classroom content. The pre-service teachers coordinated their lessons with mentor teachers to support a transdisciplinary process of teaching and learning. The mentor/mentee teams designed meaningful lessons connecting art-thinking/making processes with big ideas and interdisciplinary content. As an illustrative example, I will describe the efforts of one pre-service teacher cohort assigned to a first grade classroom investigating “community” as part of a citizenship unit.

The cohort began their unit of instruction by looking at the work of photographers depicting urban street scenes (see *Fig. 8*), to illustrate the diversity of structures inhabiting an urban community. Then, they explored the work of folk artist, Karla Gerard (*Fig. 9*), whose colorful artwork focuses on visualizing communities as imaginative dwelling sites. These two artistic views of community provided visual inspiration for representing a community, which, in turn, formed the basis of a unit plan where the first-grade students used their civic citizenship unit to compliment creative investigation (Marshall, 2006) into visualizing their own community.



Figure 8. *Broadway, looking north from Broome Street, New York, attributed to Silas A. Holmes or Charles DeForest Fredricks. Getty's Open Content Program, c. 1853 - 1855.*



Figure 9. *House trees and birds by Karla Gerard (2010).*

The pre-service teacher cohort chose “Exploring Community” as their big idea, designing their unit to investigate how communities represent aspects of a living environment. As the students explored both neighborhood and school communities, they discovered ways to illustrate and present their findings using the idea of home as a metaphor for a personal portrait. Students helped create a web of traits (*Fig. 10*) as features for their individual portraits and used various materials to create an image representing how they visually fit within their community—the symbol of home/house/building as self. Grouping these portraits together, they created a class portrait as a “Community of Learners” (*Fig. 11*).

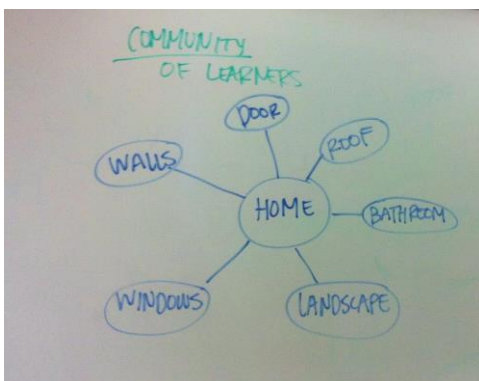


Figure 10. Concept map of features for individual portraits.



Figure 11. Visualization of “Community of Learners” constructed as a maquette supporting lesson planning praxis.

This lesson provided the students with an opportunity to view examples of a big idea, relating those images to their civics lesson, while creating portraits representing themselves within their community. STEAM-based teaching and learning wove the disciplines of art and civics into a process of critical thinking, both visually and verbally. The first-grade students explored curriculum content through a transdisciplinary lens and the partnership supported transdisciplinary instructional praxis, facilitating a learning encounter for both mentor and mentee alike.

By making the arts integral to learning, these partnership examples recognize and call witness to what the “A” in STEAM might provide for enhanced teacher and student learning encounters. A transdisciplinary STEAM curriculum model has the potential to claim the “A” not as decoration or ornament, but as a vital and enriching component for developing a vibrant learning ecology.

Expanding Partnering Beyond the Classroom

In her TED talk, *Teaching Art or Teaching to Think Like an Artist*, Cindy Foley champions a transdisciplinary approach to arts integration, one that asks students to think like artists using “transdisciplinary research” (TED, 2014). This type of research gathers information from multiple sources to support, validate, and inform critical thinking and dispositional learning practices. Transdisciplinary learning can activate integrative approaches across subject areas and promote cooperative, connected curriculum content.

As educators embrace STEAM learning, their efforts might entail inviting other educators, administrative personnel, and members of local business communities into the classroom to experience first-hand STEAM learning in action. Advocating for STEAM and acting as agents of inclusive, transdisciplinary learning could include requests for educational policy makers to work alongside students engaged in STEAM learning. Fostering experiential agency through action may shift the paradigm away from siloed learning and toward learning that is enriched from transdisciplinary encounters of discovery and embodied knowledge acquisition in creative learning ecologies.

The ecology permeating through *Voltron* suggests the necessity of recognizing specialized fields of knowledge as individually significant and vital. However, those

individual fields or parts are stronger when they “come together in an impressive feat of teamwork” (Simon Spotlight, 2017, p. 30). Like in the *Voltron* universe, our educational system recognizes the importance of discipline-specific content, yet our parts are more likely to remain detached than coming together and forming strong bonds. That said, the players within our educational ecologies have the potential to envisage strength and create impactful ties. Arts educators, classroom teachers, and administrators can embrace STEAM as a partnership supporting transdisciplinary learning through investigation, critical thinking, and visual literacy. Pre-service teachers can recognize the “A” and implement significant arts-based learning, advancing STEAM as an actionable process for building collaborative peer engagement. Participants within partnerships can explore transdisciplinary approaches to learning by considering curriculum content in each discipline—science, technology, engineering, arts, mathematics—connecting research and exploration that reflects a commitment to integrated learning.

Steam is produced from an action. STEAM can shift the paradigm of the arts from “nice to have” to “need to have,” as Maeda defined in his talk. *Voltron* can inspire us to come together as a team. Making transdisciplinary learning ecologies embraces the “A” as a partner in STEM and champions learning that can be, should be, and will be.



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Notes

¹ The quotes used within this paper are gleaned from personal notes taken during John Maeda's talk at the NAEA Conference in New York City, March 2012. His presentation

was titled, “*Super Session: STEM to STEAM, The Meaning of Innovation.*” John Maeda also wrote policy with the Congressional STEAM Caucus in 2013.

² DreamWorks Voltron Legendary Defender © 2017/8, DreamWorks Animation LLC.
<http://www.dreamworkstv.com/shows/voltron-legendary-defender/>

³See, for example, the methodology behind TAB, *Teaching for Artistic Behavior*, at: <http://teachingforartisticbehavior.org/>, and the approach described within Hetland, L., Winner, E., Veenema, S., Sheridan, K.M. (2013). *Studio thinking: The real benefits of visual arts education*. New York, NY: Teachers College Press.

⁴Thank you to Anne Uphoff, visual art educator at STEM Academy, Hollywood, CA, during the time of the pilot program. Information on Project Based Learning and the Buck Institute can be found at: <http://.bie.org/>

Imagining Physics—A Teacher's Experience

By Lawrence Herklots

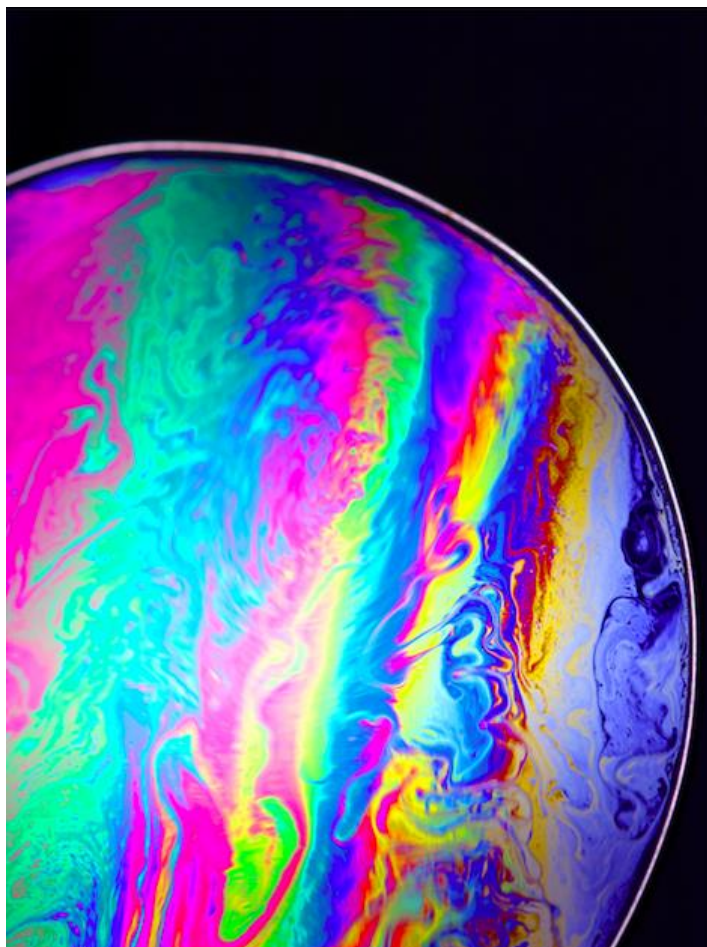


Figure 1: Interference in a soap film.

One of the photographs taken by Graham Piggott, Head of Art.

King Edward VI School, in Southampton England, is a typical English 11-18 independent day school. All our pupils study three separate sciences until they take General Certificate of Secondary Education (GCSE) examinations in the June of their sixteenth year. After GCSE they study three or four Advanced Level subjects. At this point a fairly clear arts/science divide occurs although many of those studying the sciences continue to take an extra-curricular interest in the arts.

Over the years, the physics department in particular has looked to engage the students creatively with the subject and encourage links between physics and the creative arts. As well as the usual examples of pupils' work, the department displays A1 photographs taken by the Head of Art. These are close ups of experiments carried out as part of the curriculum, but, through the photographer's imagination and skill they become something more than a record of an experiment. For example, the close up of

the interference pattern on a soap film bears a resemblance to some of the Voyager images of Jupiter.

The long science corridor makes a similar implicit link between science and visualisation. A strip of timber extends down the corridor, marked on a logarithmic scale from 10^{-10} m to 10^{26} m. Above the scale are images corresponding to sizes or distances. The first image is of a pile of gold atoms, followed by Crick's sketch of DNA. The display finishes with the Hubble Deep Field. These images fall into two broad categories; those, such as the Crick sketch, that show the imagination at work and those, like the Hubble Deep Field, that inspire the imagination. We try and get something of both in our lessons. But there is a big difference between inspiring the imagination and engaging the imagination, an altogether more active affair.

Within curriculum time, there is little space to explore ideas that lead beyond the examination syllabus. Therefore, as a physics specialist, encouraging pupils to use their imaginations and creativity in Physics curriculum, time means bringing out the imagination within the subject rather than supplementing the curriculum with 'creative' activities. This constraint can be taken as an opportunity to reconsider the nature of the subject as learned in school. The first part of this article gives an example of finding imagination in the Physics' curriculum.

As Head of Science and Technology, I have been lucky to work with a colleague in the music department in writing and producing physics-based musicals. These encourage pupils (and teachers) to use all their creative talents to celebrate and explain ideas from science in surprising and imaginative ways, building links between different areas of the curriculum, or knocking down the walls that are sometimes raised between the different areas. The second part of the article looks at this extra-curricular approach.

Drip-Feeding The Imagination

It is 3:15 on a dreary, drizzly November afternoon. The windows of the junior physics lab are dribbling with the exhalations of the previous class. I have put the apparatus on the benches: battery packs, connecting wires, ammeters, voltmeters and small lamps in their holders. I let the class into the lab for their last lesson of the day. The twenty-four Year 10 pupils are here, on a darkening Wednesday afternoon, to learn about electrical circuits.

The lesson follows its usual course: there are a number of simple circuit diagrams on the screen; I demonstrate how to set up the first, a series circuit with two lamps. The challenge for the students is to measure the current at various points. I point out the usual problems such as connecting the ammeter the wrong way around and forcing the needle to swing to the left, to the negative. I ask one of the less-focused boys what an electrical current is; "A current that's electric" he responds. I choose to ignore the facetiousness for the moment and ask for any other ideas. "A flow of electrons" comes the response from one of the more confident girls. "Exactly so, well done" I respond as a tiny seed of doubt lodges in my mind. I send the boys and girls to their benches and they begin the practical.

I spend the next twenty minutes checking and correcting the pupils' circuits so that they record the 'correct' values. As I do this, I question them to gauge their

understanding. This can be a dispiriting process. The same sort of questions come up from many groups: “But why does the current not get used up in the ammeter? How do the electrons know that there are two lamps in the circuit?” Or, more challenging for the teacher “What do these numbers on the ammeter actually show?” These are all good questions showing as much understanding as ignorance. And they set me thinking as I move from one group to another.

As physics teachers, we do not always consider the imaginative aspect of our subject. Long before Plato’s metaphor of the cave, the tradition of thinking upon which science is based developed imagined worlds. We usually assume that these worlds are a description of reality and it can be hard for a layperson (such as a teacher) to see why professional scientists would continue with their painstaking research if they did not believe that there is an objective world which their theories attempt to map in ever greater detail. Nonetheless, we should not forget that the ideas we cover in class, however precise and mathematical, have developed from the imagination of previous thinkers.

In school Physics, the imaginative constructs that ‘work’ have such explanatory strength that they become ‘facts’. This pragmatic approach will certainly help my Year 10 pupils to calculate the expected current in a circuit and state that it represents the flow of electrons. But forgetting or ignoring the role imagination plays, even in this most prosaic topic of introductory electricity, means that the pupils don’t experience the creative aspect of the subject, nor its breadth and power. *Had the girl who described electrical current as a flow of electrons merely parroted a line from the textbook without really thinking about it?* (I am fairly sure I know the answer to that question!)

In the rush to get through the syllabus, it is easy to forget that the young people studying Physics have to make their own imaginative leaps. Interpreting the twitch of an ammeter needle as a change in the flow of electrons is just such a leap. As teachers, we should consider this creative aspect whilst understanding that we are dealing with constrained creativity. If we recognise the imaginative nature of our subject, we will, through careful questioning and word choice, help our pupils recognise its creativity. We want the pupils to make a leap of imagination, even if we tell them where we expect them to land. Physics, which aims to develop a quantitative description of the world, is nonetheless a creative and imaginative activity. It is almost a truism that Physics lessons should be minds-on as much as hands-on and encouraging pupils to use their imaginations whilst performing fairly basic hands-on activities helps prevent the practical session from becoming a rather unchallenging time-filler to get through the graveyard slot of the last lesson of the day. This drip-feeding of the imagination encourages a critical approach to the work covered and a more lively debate about what is going on behind the observations of the ammeter needle. For example, when asked by a sixteen-year old ‘Did Thomson discover or invent the electron?’ you know that you have helped support a learning environment that encourages a creative approach to science.

At the end of the hour spent grappling with the simple circuits, I set a homework assignment—the pupils are challenged to come up with a new way of explaining the simple circuit rules they have been considering. A week later, the pupils submit their

work. One pupil makes a video using model cars to represent current flow, another (a keen baker, I think) has a bread delivery van dropping off loaves to represent energy transfer. Perhaps the most creative is the girl who spent hours making an electrical circuit board game with detailed rules (which make sense), cards, energy chips, and circuit components to build across a board, turn by turn. Such occasional homework activities, developing from a teaching approach that recognises the role of imagination within the subject help the pupils recognise and embrace the model-making nature of physics without taking away their confidence in ‘the right answer’.



Figure 2: ‘Welcome to Gedanken’. Cast of reduced, touring version September 2018

The Physics Musicals

‘Einstein Year’ in 2005 promoted discussion of Einstein’s work in schools and colleges across the country. At King Edward VI School, we developed ‘Einstein – The Musical’ to give pupils an opportunity to use their talents and creativity in a novel manner. The show was based on the reflections of the older Einstein on the work he carried out in his youth. We tried to give analogies for his all major theoretical interests of 1905. For example, a lone dancer, singing of her solitary life whilst waltzing across the stage in a straight line represented a particle in a vacuum. When joined by a group of jigging morris dancers (complete with sticks and bells), she was pushed in all directions in a visual metaphor of Brownian motion.

‘Einstein the Musical’ was a physics lecture set to music with songs separated by straightforward explanations from the older Einstein. Our second musical, ‘That Certain Uncertainty’, had a far stronger narrative arc—its strapline ‘A musical comedy of love, loss and quantum physics’. A farce set in a seaside hotel in 1927, it was an extended metaphor for aspects of quantum physics. The two entrances to the stage constantly evoked the two-slit thought experiment. The narrative focused on two sets of guests that had to be kept apart by the hapless hotelier. One group, three physicists on the way

to Copenhagen, excitedly discussed recent advances in their field—thus informing the audience of the physics.



Figure 3: ‘That Certain Uncertainty’, Winchester Theatre Royal. The characters are arguing about Quantum Physics

‘Welcome to Gedanken’, which concerned the absence of evidence the luminiferous ether, played in 2017. Another farce, the narrative, set in 1905, touched on the rising tensions in central Europe. The female lead, Mrs Staveley, believes that scientists have been kidnapped and taken to ‘Gedanken’—a mysterious country in central Europe. She suspects a young physicist of forming connections with Gedanken scientists and so lures him to a disused theatre in which she has persuaded a motley bunch of individuals to dress and speak as natives of Gedanken. Their aim is to prise secrets from the scientist...

The play explored the null result of the Michelson-Morley experiment, taking in a number of other ideas from physics, philosophy and psychology. The play ends with the publication of Einstein’s statement of the non-existence of the ether. Einstein’s Gedanken experiments have been misinterpreted as experiments taking place in Gedanken. As the ether disappears from Physics, Gedanken vanishes from geography (Figure 4).

We developed these plays for a number of reasons: they give teachers and pupils from different disciplines the chance to work together and discuss the ideas behind the somewhat ludicrous plots; they get a great many pupils involved, and they give the audiences a chance to learn some Physics whilst enjoying all the usual pleasures of musical comedy and farce. Lastly, they give all those involved an understanding that creativity and imagination are behind all intellectual and artistic endeavours. And they’re fun.



Figure 4: ‘Welcome to Gedanken’ Winchester Theatre Royal 2017. “All science is Physics or stamp collecting.” Ernest Rutherford

Conclusion

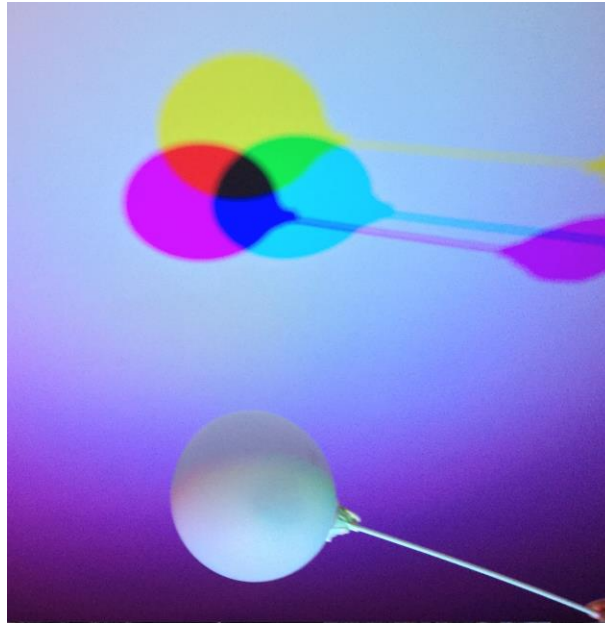
Former pupils often tell us that their involvement in the physics musicals was one of the highlights of their time in school, and over the years they have returned to see the latest productions. They remember the physics content as much as they do the songs and choreography. The plays demonstrate that the creative arts require as much intellectual effort as Physics requires imagination. Recognising the differences between disciplines whilst celebrating their commonalities provides a rich approach to the study of both arts and sciences. However, we shouldn't only rely on occasional extra-curricular events to support creativity in science but embed it in the day-to-day approach to the subjects as studied in school.



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A Colorful STEAM Activity

By Melike Yigit Koyunkaya, Turan Enginoglu, Burak Karabey and Kemal Yurumezoglu



The shadow experiment, performed with three sources of light RGB and the different shadows formed on the screen.

In order to explain a phenomenon in depth, we have developed a strategy focusing on asking questions, looking for answers, and reaching new conclusions with scientific curiosity that arouses a new problem following each answer. In this sense, as a team, we started working to adopt a science, technology, engineering, and mathematics (STEM) education model that is commonly used in many countries. The first part of the activity proposed in this paper was developed in the context of STEM education. However, recently, research emphasizes the importance of art and esthetics in innovative approaches for solving real-life problems. With this emphasis, a science, technology, engineering, arts, mathematics (STEAM) education model was developed by adding 'art' to STEM education (Baker, 2014). The existing studies argue that the arts are crucially important for developing some skills such as creativity, observation, visualization and handcraft, which constitute the base of the scientific thought process (Cantrell, 2015). The arts also support understanding the engineering design process, conducting this process, and improving the spatial thinking, which are important in learning mathematics (Yokana, 2014). Thus, we, as a team, developed the second part of the activity by considering the integration of the discipline of art in order to unify the phenomenon of color with our visual and esthetic features.

Color is an interesting phenomenon to work on for different disciplines. A question, "Could shadows be colorful?" was our starting and base point in this work. The main aim was to ask a creative question and to look for an answer. That's all. In the

process of answering the creative question, we employed the perspective of the famous French philosopher Gaston Bachelard, and we attempted to digress from the common perceptions as Bachelard suggests.

The following step was a completely exploratory process. When the answer of this question explains the concepts of full shadow, partially full shadow and multilayer shadow in a straightforward and colorful way, the appearance of the second question, “could we build a mathematical model for colors and light and pigments and transition of these colors?”, revealed a thought to find an interdisciplinary answer. The second question formed another answer that forced the team to work in more depth. We were able to model the relationships between light colors and pigment colors in a mathematical way through a colorful shadow experiment, in order to prove it using technology, and to constitute an empty set that is visible, which was an impressive result. When we integrated the discipline of art into our work, we started to see colors more attractively. Finally, we showed that a scientifically-based method could be used in painting.

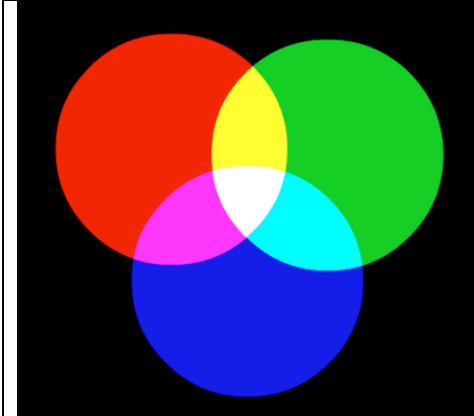
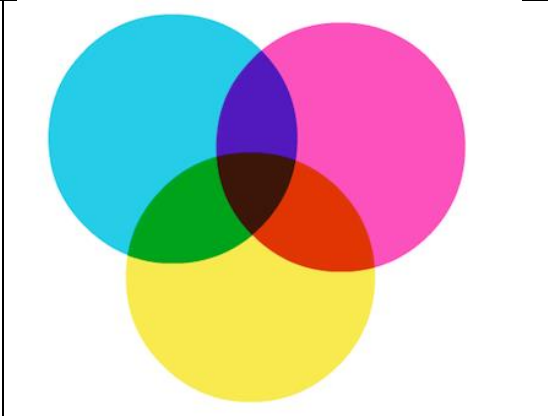
As a team, we developed some activities that could be used to teach different subjects in different grades by integrating science, technology, art and mathematics through the use of an integrated STEAM education framework. While the developed activities support students’ conceptual understanding and provide opportunities for them such as with gaining STEAM literacy and 21st-century skills, as well as preparing them for their future jobs, they also provide opportunities for teachers to develop their content knowledge and pedagogical-content knowledge by presenting different applications (National Research Council (NRC), 2014). In addition, in the content of these activities, we will also explain how to integrate different disciplines, how to manage the teaching processes, how to support students in their learning and the roles of teachers in detail. In this paper, two activities are discussed in two stages.

Section I: How do the shadows build the relationships between colors of light and pigments from a mathematical perspective?

In this work, a meaningful relationship between colors of light and pigments was built with the help of shadow, partially full shadow, and multilayer shadow using rectilinear propagation of light. This context was interpreted in a mathematical perspective by using the concept of sets.



Introduction

It is taught that the primary colors of light are red–green–blue (RGB), and that the secondary colors are Cyan–Magenta–Yellow (CMY). To make the transition from colors of light to colors of pigment, a consistent point is necessary. The main connection is that the pigment colors, *Cyan, Magenta and Yellow*, are formed when the primary colors of light are added one on top of another. White (White light) is obtained when the primary colors of light are added one on top of another. On the other hand, the primary colors of pigments form *black* (lack of light) (Figures 1(a) and 1(b)).

	
<p>1(a) The primary colors of light (RGB) and their mixtures on a dark setting.</p>	<p>1(b) The primary colors of pigments (CMY) and their mixtures on a white setting.</p>

A Shadow From a Physical Perspective

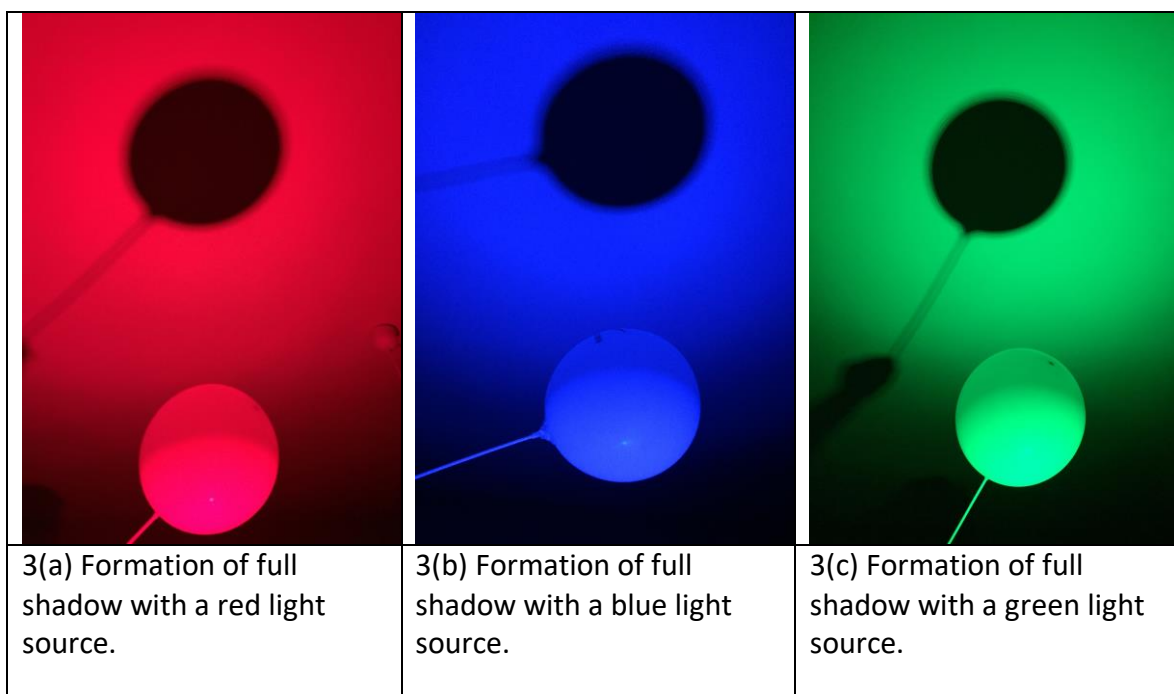
In this study, based on the phenomenon of the linear dispersion of light, we suggest a STEM activity focusing on physical and mathematical perspectives to reason about the formations of full shadows, partial shadows and multilayer shadows. The materials used in this experiment were: light sources made up of red, blue and green LED lamps, a 12-V DC adapter, an opaque white balloon and a White screen (white wall) (see Figures 2(a) and 2(b)).

	
<p>2(a) Materials for the experiment setup; red, blue and green lamps, a white balloon and a 12 V adapter.</p>	<p>2(b) The red, blue and green lamps that light up in the experiment.</p>

Stage 1: How is a shadow formed?

In the first stage of the experiment, the red, blue and green LED lamps were arranged in an equilateral triangle-shape (such a triangular design is useful to follow the tracks of the light radiated from the light sources) (Yurumezoglu, 2009), and connected to the city voltage via a 12 V adapter (see Figures 2(a) and 2(b)). The balloon (opaque obstacle) was

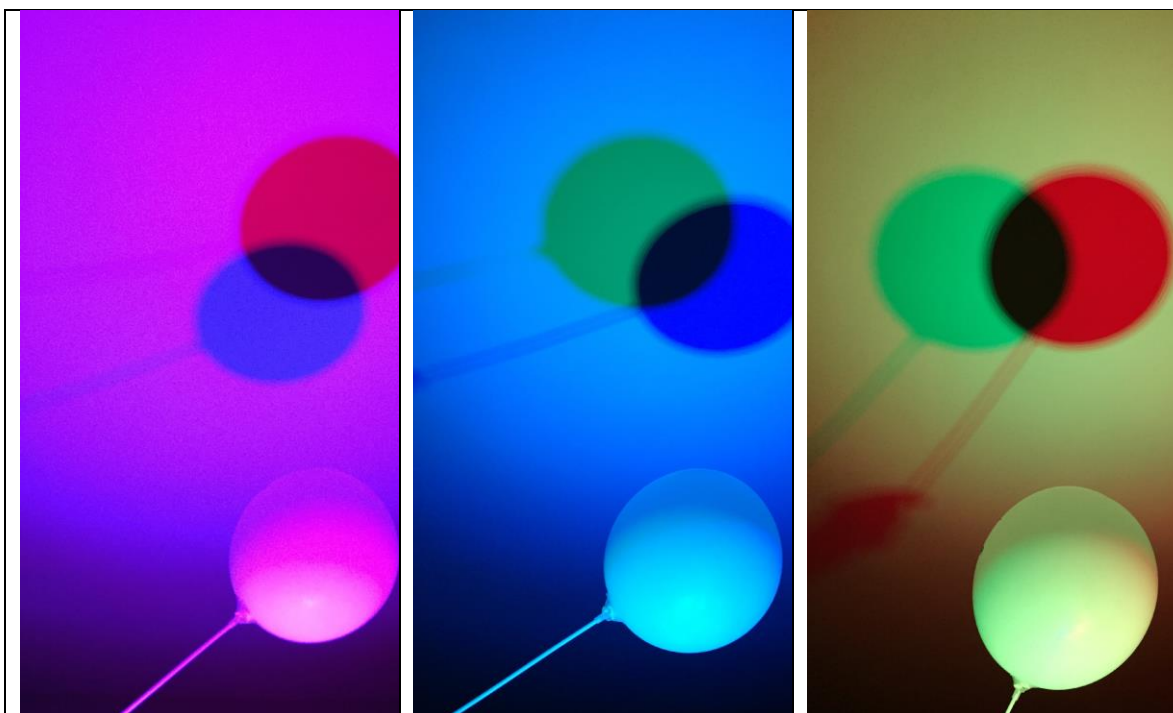
placed in front of red, blue and green lamps, then each lamp was lit one at a time in a completely dark environment and the result was observed on the screen. The area in the back of the obstacle where light could not reach was black/dark whereas the other areas where light could reach were the same as the color of the source (see Figures 3(a)–3(c)).



When light rays radiating from sources in a dark environment fall upon an opaque obstacle, the light cannot brighten the areas in the back of the objects due to the linear dispersion of the light. Because of this, there will be dark areas where light cannot travel behind the objects. The dark area formed as a result of the linear dispersion of light is called a full shadow. Therefore, it is concluded that a light source, an opaque object (obstacle) and a screen (background) is what is needed to form a shadow.

Stage 2: How is partial shadow formed?

The lamps in the setup in Figure 2 are now used to remake the experiment by lighting two of them simultaneously. In this stage, the blue–red, blue–green and lastly, the red–green lamps are lit while an obstacle is placed in their way (an opaque white balloon) and the corresponding shadow formations are observed on the screen (see Figures 4(a)–(c)).



4(a) Formation of partial shadows with red and blue light sources.

4(b) Formation of partial shadows with blue and green light sources.

4(c) Formation of partial shadows with red and green light sources.

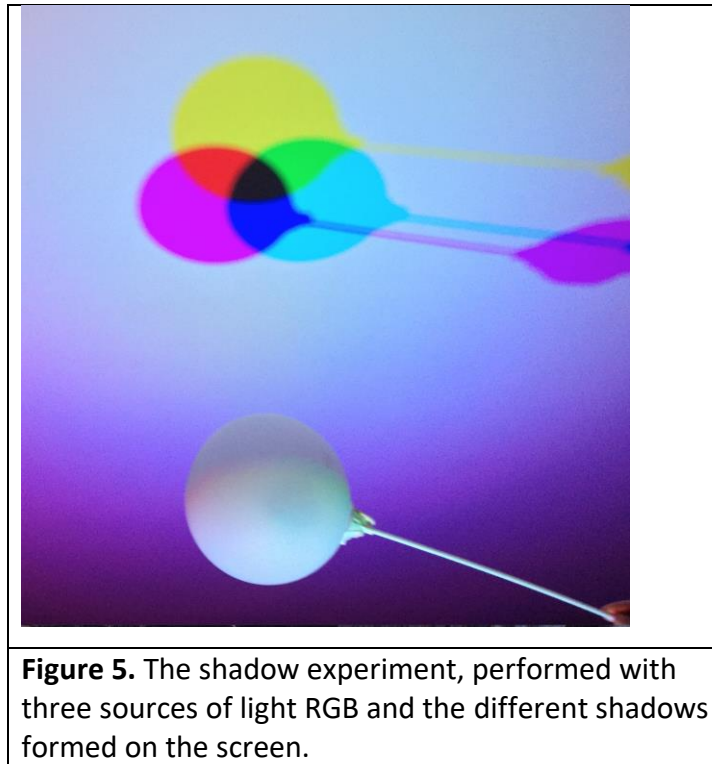
Here, let us first look at the parts on the screen and balloon where the rays from the light source can reach and those are not in shadow. We reach the following conclusions: the mixture of light colors reflecting on the screen are observed to form the colors **magenta** from **blue + red** (see Figure 4(a)), **cyan** from **blue + green** (see Figure 4(b)) and lastly, **yellow** from **red + green** (see Figure 4(c)).

We can explain the second step of the experiment in the following way: We observe dark/black areas because no rays of light from any source of light reach the dark part in the middle part. As in the previous experiment, we call this central area an area of full shadow. We call the area peripheral to the black/dark part a partial shadow because at least light from a single source reaches this area. There are two partial shadows (colored shadows) on the screen. Each colored area received light from one source and could not receive light from the other source because of the barrier (see Figures 4(a)–(c)). Using colored lights in this experiment was instrumental to differentiate between full and partial shadows. In addition, when there are two light sources, we can see that the partial shadows take the color of the illuminating source.

Stage 3: How are multilayered shadows formed?

In the last stage of the experiment, all three lamps (red, green and blue (RGB)) are lit simultaneously and an obstacle is placed in front of them to observe the formation of the shadow. In this case, we observe that the areas where the shadows intersect are full

shadows (of black color), and the areas surrounding the full shadow are colored shadows composed of primary and secondary colors (see Figure 5).



If we bring the number of light sources up to three, we can see three different types of shadows and areas of many colors (see Figure 5). Here, the area appearing to be black is a full shadow and no light can reach there from any source. Besides this, there are areas of red, blue and green where light only from the corresponding color source can reach. Finally, the areas that are colored yellow, magenta and cyan on the screen are illuminated by two sources, and light from one of the sources does not reach at all. From this point of view, it is concluded that the color of the shadows formed depend upon which light reaches the screen.

At the end of the experiment, we realized that the shadows formed with the RGB light sources (see Figure 5) possess the primary pigment colors seen on the white background. This also reveals to us that there is a significant relationship between the color of the light and the pigment color. In the presented experimental design, the different types of shadows formed with the obstruction of light are actually corresponding to the absorption of light colors by the mixture of pigment colors.

Shadow From a Mathematical Perspective

When we look at the shadows formed in Figure 5, some of us may be reminded of the concept of sets, that is, a set of three elements and the intersections between these elements. If we characterize colored areas as sets of the primary colors red (R), green (G) and blue (B), we can express the intersection of the blue color and the red color as magenta ($B \cap R = \text{magenta}$), the intersection of the green color and the blue color as cyan

(G-B = cyan) and the intersection of the red color and the green color as yellow (R-G = yellow). Finally, the intersection of the three colors can be expressed as white (R-G-B=W) (see Figures 5 and 6). Then, we obtained the following figure (Figure 6) by eliminating the colors that are not on the colorful areas.

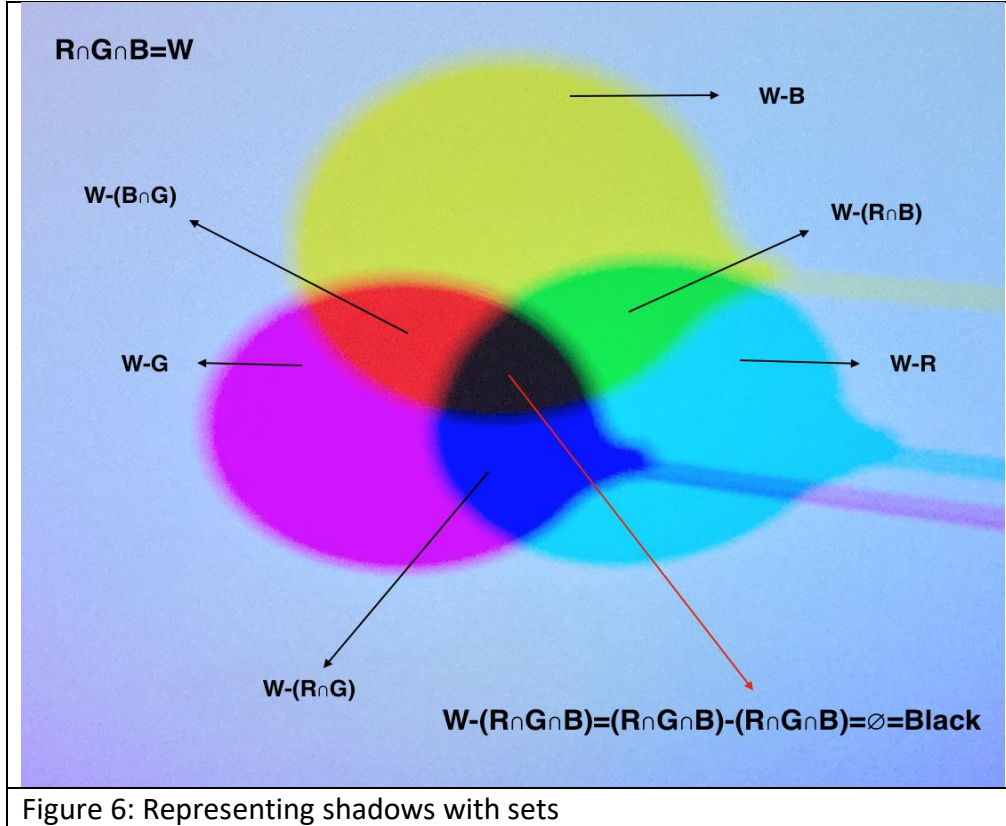


Figure 6: Representing shadows with sets

The experiment process related to the shadows can be watched by scanning the given QR Code here:



Now let us find a mathematical model in the language of sets to express the black area/shadow formed with three light sources and the opaque object. We can describe this shadowed area in words as the intersection of the RGB colors on the screen or the area where no light from any of the light sources has reached. Therefore, the area can be modeled as

$W-(R \cap G \cap B) = \emptyset$. We can further elaborate on this equality to verify the expression of the black area.

As we indicated before, for white light to appear on the screen, all of the primary light colors radiated from the sources must intersect. We can express this as an equality; $W = R \cap G \cap B$.

If we substitute the corresponding set in the equality $W - (R \cap G \cap B) = \emptyset$, we obtain the model for the absence of the white light (W) that shows the area of black/shadow.

$$(R \cap G \cap B) - (R \cap G \cap B) = \emptyset$$

Since the difference between a set and itself is an empty set, the black or unilluminated area shown in Figure 6 could be named as an empty set. A mathematical expression for the area that we are accustomed to perceive and call a dark or full shadow in daily life as an empty set creates a subjective interpretation of the observations. Also it provides a concrete and physical representation for sets and empty sets used so frequently in mathematics. The same operations will be done with all the colors in Figure 6, and we obtain the Table 1.

Color (Set symbol)	Set	Complementary operations with sets	Complement color (set symbol)
White (W)	$W = R \cap G \cap B$	$W^c = (R \cap G \cap B)^c = R^c \cup G^c \cup B^c = \emptyset$	Black (\emptyset)
Magenta (M)	$W - G$	$(W - G)^c = (W \cap G^c)^c = W^c \cup (G^c)^c = \emptyset \cup G = G$	Green (G)
Yellow (Y)	$W - B$	$(W - B)^c = (W \cap B^c)^c = W^c \cup (B^c)^c = \emptyset \cup B = B$	Blue (B)
Cyan (C)	$W - R$	$(W - R)^c = (W \cap R^c)^c = W^c \cup (R^c)^c = \emptyset \cup R = R$	Red (R)
Red (R)	$W - (B \cap G)$	$(W - (B \cap G))^c = (W \cap (B \cap G)^c)^c = W^c \cup ((B \cap G)^c)^c = \emptyset \cup (B \cap G) = (B \cap G) = W - R$	Cyan (C)
Blue (B)	$W - (R \cap G)$	$(W - (R \cap G))^c = (W \cap (R \cap G)^c)^c = W^c \cup ((R \cap G)^c)^c = \emptyset \cup (R \cap G) = (R \cap G) = W - B$	Yellow (Y)
Green (G)	$W - (R \cap B)$	$(W - (R \cap B))^c = (W \cap (R \cap B)^c)^c = W^c \cup ((R \cap B)^c)^c = \emptyset \cup (R \cap B) = (R \cap B) = W - G$	Magenta (M)

Table 1. You can prove the accuracy of the mathematical operations in the table by using the Invert Color feature of your smart phone.

Conclusion (Section I)

The shadows formed based on the linear dispersion of light appear as areas of partial and multilayered shadows, each displayed as photon clusters and combinations and thus the concept is expressed as being mathematically meaningful. This integration of physical phenomena and mathematical concepts has not only given the concept of shadows a mathematical significance but also provided a pleasant example of the notion of the empty set. The area expressed in the shadow experiment as black/dark corresponds to the empty set representing the absence of light.

Section II: Exploring the Theory and Application of Complementary Colors

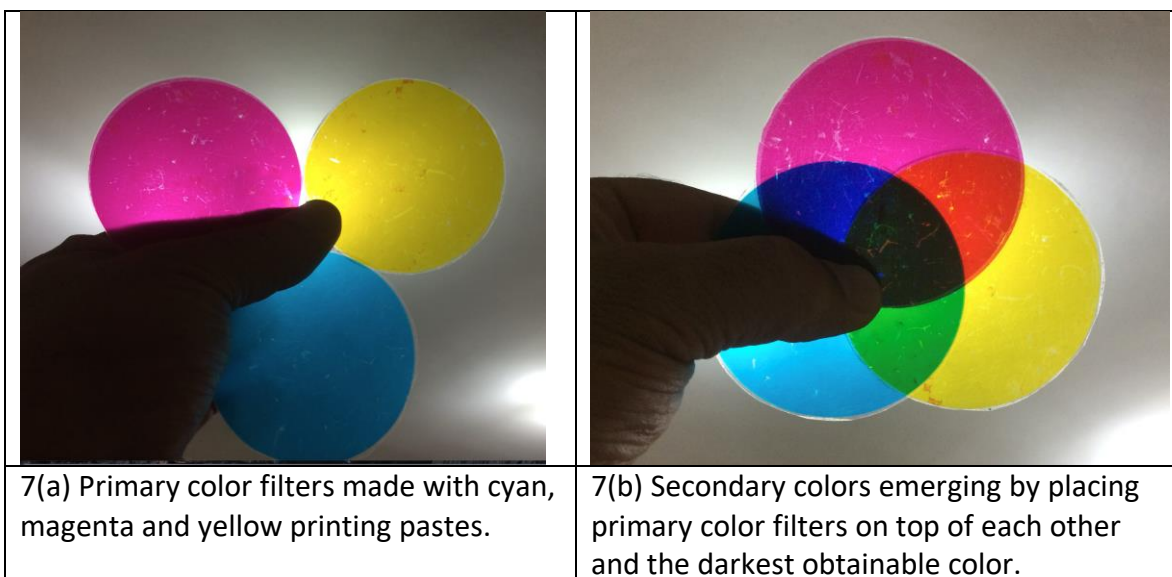
In this section, we explore the theory and applications of complementary colors using a technology-based activity designed from the perspective of STEAM education.

Complementary colors and their areas of use were examined from the perspective of Physics, Mathematics and Art, respectively.

Complementary Colors From Physical Perspective

When we combine the pigment colors of cyan, magenta and yellow with the printing pastes in Figure 7(a), we produce the colors shown in Figure 7(b). Complementary colors for pigment colors are the colors that complete the mixture to create black. In this case, cyan is complementary to red, magenta is complementary to green and yellow is complementary to blue. Complementary colors for pigment colors are the colors that complete the mixture to create black.

Here, we observe that the point where **blue** meets its complementary color **yellow**, (the mixture of magenta + cyan) is **black**. This phenomenon depicts that the pigment color **yellow** has absorbed the light color **blue**. Similarly, the pigment **magenta** absorbs the light color **green** (Cyan + Yellow), while the pigment **cyan** absorbs the light color **red** (magenta + yellow). In other words, each filter absorbs the color which is its complementary one. This simple experiment demonstrates that the reflection/transmission of colors is complementary to their absorption in the interaction of matter and light.



Observing Complementary Colors with the Help of Technology

The Invert color feature found on Smart phones and in the Photoshop program offers us the opportunity to use this feature in teaching the topic of complementary colors. We use the invert color feature available on our smartphones to look at the mixture of cyan, magenta and yellow (CMY) that we can obtain with our filters. We observe that the colors turn into what we see in Figure 8. The colors appeared on the screen are the light colors red, green and blue (RGB) and their mixtures. Based on the complementary colors theory and with the help of a feature made available to us through technology, we can make surprising discoveries about the colors that an object will absorb in nature. An example was given in Figure 9(a)-(b).

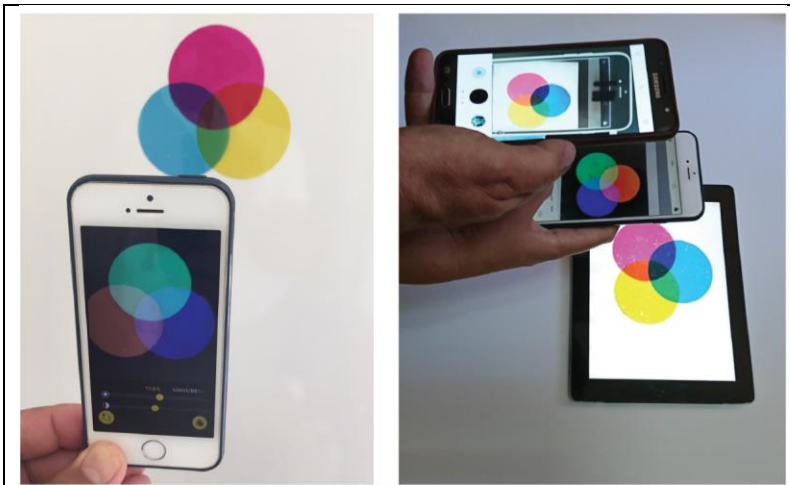
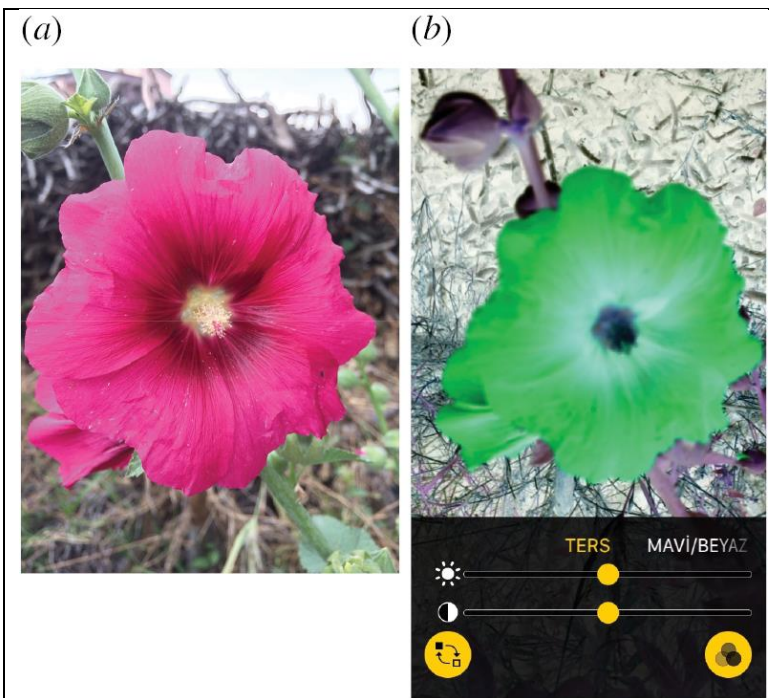


Figure 8. The complementary colors of the primary colors and mixtures obtained with magenta, cyan and yellow pigments in the background, displayed with the Invert color feature on our smartphone.



9(a) Colors reflected in a flower.

9(b) Colors (complementary) absorbed in the same flower.

Complementary Colors from an Art Perspective



Figure 10. (a) Turan Enginoğlu, flowers in a vase, 2007, oils on canvas, 70 × 100 cm, private collection. (b) Complementary colors of 'Turan Enginoğlu's work'.

In short, the use of complementary colors in Turan Enginoğlu's work has made the painting more vivid and color-harmonious. The distribution of the complementary colors set a balance between reflection and absorption of light in the painting. The colors obtained by mixing the paints absorb the light, making the colors darker, while the complementaries of these colors absorb the light less and produce light tones. Controlling the balance between the reflection and absorption of light when using the paint pigments could enable the artist to transfer his/her emotions onto the canvas. This is made possible by the artist's application of knowledge gained about the basic elements of complementary color theory. The artists who have made their mark on art history have done exactly this.



Figure 11. Complementary colors obtained from cross-sectional details on the painting using the Invert feature.

Conclusion (Section II)

The three different perspectives described above lead to the following basic conclusions. Primary colors of light added one on top of another produce *white* (white light) while pigment colors produce *black* (lack of light), meaning that in colors of light, the complementary of a color is the color that will complete it to produce white while in pigments, the complementary is the color that will complete it to create black. This leads us to the outcome that light and pigment colors are complementary to each other. Based on this, we can also say that the color of light reflected by an object is complementary to the color of the light absorbed by an object. Knowing the color of the light reflected from an object gives us a clue as to which color of light the object absorbs. Additionally, the complementaries of light or pigment colors can be found by using some of the equations related to the concept of sets in mathematics and this could be beneficial and educational in terms of demonstrating the consistency of complementary of colors. Finally, examining noteworthy works of art allows us to prove that the complementary colors used appropriately in many of these pieces have been used correctly, in proportion and harmoniously.



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Turning Wood: STEAM Education and Maker Pedagogy

By Allan MacKinnon



I started my career in education in the classroom during the mid-seventies teaching science in a small rural elementary school in Southern Alberta. We were encouraged to use a “hands-on,” inquiry approach in our teaching. Later, the movement was critiqued and the slogan of “hands-on, minds-off” appeared on the lips of some people. They claimed that kids in schools were having a lot fun with activities, but they weren’t necessarily learning science as had been intended by the curriculum and program designers. Still later the slogan of “hand-on, minds-on” was taken up in retaliation, as it was thought that a “practical” approach to curriculum (Schwab, 1969) would more likely bring about the authentic engagement of pupils at all levels, and that this level of engagement would result in higher levels of achievement and more relevance in learning.


The rhetoric of science education in the sixties and seventies helped to put me on a practical pathway in teaching general science to elementary pupils—something I had not been formally prepared to do; I was an intending secondary school biology teacher when I was hired as an elementary science specialist. But it was natural for me to teach general science in an inquiry format, partly due to my undergraduate study and engineering experience—I had worked as an engineering technician after graduating with an undergraduate degree in science. I was very familiar with working in practical ways using science in the study and design, construction, and testing of materials (such as soils, concrete, asphalt, steel, and so on). I loved building things; I have always been a builder, spending hours upon hours in the wood shop since the age of seven. Building things with my students came naturally. For example, my grade six students and I built all of the apparatus needed for the Elementary Science Study¹ program I used in my nineteen seventies classroom, including balances, pendulum racks, inclined planes, and such.

My early experiences in the sciences and engineering, together with the ethos of the time—favouring a practical approach in the classroom as mentioned—paved the way to a joyful career teaching science, first at the elementary school level and later in the faculties of education of four Canadian universities. I’ve thrived on this practical approach since the beginning. Hands-on science became a jumping off point for me as a generalist grade six teacher a few years later when I adopted a project-based approach to integrating curricula—a move that opened up my life as a teacher even more. In turn, this practical approach to teaching provided a solid foundation for my career as a professor of science education. Today, as a continuing enthusiast for interdisciplinary approaches in schooling, I am very excited about the addition of the “A” to STEM education. I believe the arts have much to offer science, technology, engineering and math—the combination can be powerful and the arts can be pivotal in the synergy created among these disciplines.

One example comes from my own journey as an educator (and musician). About fifteen years ago I learned how to make wooden pens on a small lathe. This was intriguing, as it became a way to bring my love of playing guitar to bear upon academic writing: if I could make a pen from fine wood so that holding and using it for writing might remind me of the finger board of a guitar, perhaps I would take more artistic license in my academic life. Making wooden pens could become a pathway for developing more confidence, expression and precision in my writing.

¹ Elementary Science Study (ESS), Education Development Center, 55 Chapel St., Newton, MA 02160 (617) 969-7100; Fax: (617) 965-6325

While the connection between writing and music became easier to make, the experience of learning to turn pens led to much more than I initially anticipated. I found that turning different kinds of woods brought new understandings of the physical and sonic properties of the various ‘tone woods’ used to build guitars. This bridged Physics and Music to an earlier career I had as a materials engineering technician before becoming a teacher. I came to understand the qualities of the dense hard woods more deeply through cutting them. For example, the ebony of the example shown is the most dense and stable wood I know and as a result it takes the longest to cut and requires frequent sharpening of the cutting tools. Despite its hardness, though, ebony is easy to cut uniformly. Figured (curly or fiddle-back) maple, on the other hand, is difficult to cut evenly, as it involves pressing in to cut the more dense wood of the curly parts in the grain and then immediately easing back on the softer parts so as not to gouge the wood. The figure in the wood appears as hills and valleys—like *waves* of sand or water. The density of the wood varies where the tree is stressed, branch stemming off the think of the figure as reinforcement bars set in ‘glass-like’ qualities of a rosewood can be like that is prized by my ears as a guitar player in new and interesting conceptual understanding. brought a deeper appreciation for their tonal



across these waves. It occurs such as beneath a large main trunk. I learned to Nature’s rebar (like iron concrete). I learned how the good piece of Brazilian crystal, giving a bell-like tone aficionados. What I knew in came to be felt in my body ways—as an embodiment of Cutting the tone woods understanding and qualities. This brought together ways of thinking about material science and engineering with ways of understanding and being as a musician and, indeed, as an educator.

Turning pens took me much deeper into the study of pedagogy. Coincidentally, my doctoral advisor, Gaalen Erickson, had also taken a keen interest in turning wood, albeit at a different level and magnitude. A few years ago in the midst of a writing project we were doing together, I gave Gaalen a wooden pen I made for him. He took it, smiled, and brought out some of his recent turning projects—he’d been taking lessons in making wooden bowls as part of a wood turning guild. We’d both been turning for a while, not knowing this was a mutual interest we shared. More recently we’ve been turning together and Gaalen has been teaching me the techniques of bowl making on a big lathe at his shop. I took him some of the choice pieces of wood from a big cherry tree that was removed from my property and he was generous enough to offer to teach me turning on the big lathe using some of it. Gaalen is retired now, but this activity has kept our pedagogical relationship alive—he is still my teacher and I am still learning from him and the relationship we share. It’s been an occasion for me to reflect on what teaching is and what it can be, the importance and centrality of the teacher-learner relationship, and the nature of knowledge and understanding that develop within that relationship, particularly through *making*.



In graduate school, Gaalen was a role model for my learning about doctoral supervision. We spoke regularly about teaching and learning in the context of his tutelage. We were both keenly interested in Donald Schön's (1983, 1987) ideas about reflective practice, and my dissertation involved developing a conceptualization of a *reflective practicum* in the teaching of science. There were both conceptual and professional interests invested in his mentorship. Schön provided a language and set of constructs that described what I was experiencing in graduate school, as well as what we might desire in the education of all teachers. One of Schön's models is called the *hall of mirrors* model of coaching reflective practice, wherein the coach's handling of the student models

the very practice that the student is attempting to acquire. This creates a hall of mirrors for the student: the student can feel the effects of the coach's pedagogy at the same time as developing his or her own pedagogical practices with others.

Later, in my career as a professor of education, I find that to some extent I've modeled myself after Gaalen in my own supervision of graduate students. Now, more than thirty years later, he is my teacher again at the big lathe, helping me to develop my skill in turning bowls. The learning process for both of us I think has been 'in the doing' or 'in the making.' We took turns at the lathe, Gaalen *showing and telling* and me *listening and imitating* (Schön, 1987) gradually becoming able to reproduce his motions in my own body—the stance at the lathe, the hold on the cutting tools, putting the body into the work, the angle of the cutting edge, and so on. I made a [short video](https://goo.gl/xx1pEd) (<https://goo.gl/xx1pEd>) of us making a bowl together, he and I taking turns filming or turning. When I found the 'sweet spot' of the cutting edge of the gouge or bevel against the wood as Gaalen had demonstrated, the wood shavings would come streaming up over my shoulder (this is evident at times on the video). The video depicts Gaalen demonstrating (he is wearing a silver wrist watch) and me learning to use the big lathe *at the elbows* (MacKinnon, 1996). I added a song to the video that I wrote and recorded called, *Simple Lesson*. The song offers a Buddhist interpretation of teaching—one referring to the so-called 'wholesome roots' of *alobha*, *adosa*, *amoha* (generosity, kindness, selflessness) and *karma* (action, doing).

What I like about this story is the reciprocity between the feeling and process of my own learning and that of Gaalen, or indeed my students—it's passed on from Gaalen (and his teachers) in the special relationship we had during my doctoral studies, and from there to the special relationships I share with my own graduate students.

Examining my learning (what I am *reaching* for) provides pathways of reciprocity and respect to understanding the learning of my students (what they are *reaching* for), the pupils in their classrooms, and in the communities in which we all live. I think of it as a window to understanding the very nub of human nature, this element of *reaching* for something. Whether it's a new tool, a fresh understanding or perspective, or an opportunity to be taken, the act of *reaching* brings a new breath to life itself. Hope, hard work, determination, are linguistic forms used to describe this, but basically it is why we get up in the morning, as though each day (hopefully) brings a new act of attempting something—"we make ourselves up as we go" (MacKinnon, 2013, p. 18).

I hope my example of turning wooden pens and bowls provides a good example of maker pedagogy that goes beyond commercialized curriculum materials and slogans in teacher education (Sator, Bullock, & MacKinnon, 2018). People acknowledge and write about embodied learning, and my analysis of turning might be thought of as an attempt to articulate this embodiment. Learning takes place in the body and in the mind, the body informing the mind, and the mind informing the body. The teacher and student work together to form something, to make something useful and perhaps beautiful. Their act of creation is much more than making a pen or a bowl—it is an act of making each other as well, the teacher and the student. I am hopeful that the positive practical movements I see in schooling today are sustained and nourished—place-based learning, project-based learning, nature-based learning, garden based—these are all venues of human endeavour that contain potential for the teaching, learning relationship to thrive in this way and I hope that our institutions continue to support and encourage this form of learning by doing in the STEAM initiative.



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Engaging Children in Engineering Using Digital Storytelling

By Glenn Ellis, Beth McGinnis-Cavanaugh, Alan Rudnitsky, Sonia Ellis and Isabel Huff



Figure 1: *Talk to Me* and *TimeTilter* Novels (available [here](#) and [here](#)).

The role of engineering is expanding in K-12 education in the United State. This is due to the need for graduating engineers who are better prepared to meet the challenges of the knowledge age; for educating a technically literate public; and for diversifying the engineering field to increase the percentage of women and underrepresented minorities in the workforce. Unfortunately, there are few resources that are grounded in the research on teaching and learning available to support K-12 engineering educators. To address this need, we have created *Through My Window*, a story-based, idea-centered, multimedia learning environment for middle school children to learn about engineering.

In order to engage the kind of caring needed to engage children in deep learning, the design of *Through My Window* is based on Imaginative Education (IE) (Egan, 1997; Egan & Judson, 2016). In this approach, instruction supports a developmental sequence of five types of understanding—each with an array of cognitive tools—that enable learners to make sense of the world in different ways. Of the five types of understanding, “mythic” understanding and “romantic” understanding are the narrative structures most appropriate for middle school children. Mythic understanding begins as learners develop enough linguistic ability to discuss and understand things they haven’t physically experienced. At this age, they become aware of a sense of mystery that surrounds knowledge, and they are comfortable in a world containing myth and fantasy. Romantic understanding begins as learners search for the edges of the world they are beginning to comprehend. Among the cognitive tools associated with the five types of

understanding, the most important tool is narrative. Stories ground complicated concepts in concrete terms and connect abstract ideas with emotions and events. (Visit the imaginED website (www.educationthatinspires.ca) to find out more about the theory and practice of Imaginative Education.)

Overview of Through My Window

Through My Window is an online curriculum with parts that can be combined in different ways to meet varying teacher needs. All can be accessed through our educator website: teamthroughmywindow.org. The website also includes a teacher's guide with chapter summaries, video tutorials, vocabulary words, writing prompts, off-line activities, and pathways for integrating online and offline curricula.

At the heart of Through My Window are two novels: *Talk to Me* and *Time Tilter* (Figure 1). In each novel, children are introduced to relatable characters who use engineering to solve problems. The novels are offered in both print formats and online formats; the online formats are accompanied by an audio version of each chapter. Three story-based online learning adventures accompany *Talk to Me*. In these adventures, children join the *Talk to Me* novel characters to learn about artificial intelligence, engineering design, and engineering ethics. One online learning adventure accompanies *Time Tilter*. In this adventure, children become part of the storyline by hacking into a fictional website, where they learn about biomimicry and engineering design to help the novel's characters.

Talk to Me Novel

In *Talk to Me*, fourteen-year-old Sadina Reyes is fighting the clock to keep her mother from being arrested for a crime she didn't commit. Sadina thinks her little sister, Maddie, has information that could prove their mother is innocent. There's one big problem: Maddie can't talk. She has selective mutism, an anxiety disorder that makes it impossible for her to talk about what she's seen.

Sadina searches desperately for a way to help her sister communicate. Sadina's friends join together to help her transform Bella—Maddie's robotic cat—into Chattercat, a talking robot that just might get some answers from Maddie. In using the engineering design process to build the robotic cat and solve the mystery, Sadina and her friends learn about artificial intelligence and experience ethical dilemmas paralleling the kinds of situations that professional engineers and technologically literate citizens might face.

Talk to Me Learning Adventures

Online learning adventures allow users to go beyond the novels and join the *Talk to Me* characters to play a central role in three additional stories. The narrative in each of these adventures is advanced by a variety of means, such as interactive graphic novels that frame the stories; games and puzzles that the users need to solve to complete the story; numerous videos that are integrated into the story; online journaling for recording and sharing ideas; and other devices.



Figure 2: Sample screenshots from the introductory graphic novel in the Rio's Brain learning adventure. These images show Rio coming to Sadina's house for help; Rio telling the backstory of his camping trip; Rio describing his fall off a cliff; Rio in the SCARE laboratory; Rio looking at his own brain in a vat; and Rio and Sadina looking up at the mysterious mansion of Dr. Ecks.

The adventures include:

- **Rio's Brain:** The adventure begins with a graphic novel in which Sadina's friend Rio is separated from his brain by the evil SCARE organization (Figure 2). Users are called on to help Rio by exploring the virtual mansion of the mysterious Dr. Ecks to determine if an artificial brain can be used to save Rio. Along the way they discover videos of amazing artists, musicians, a robotic table tennis player, and others that are prompts for them to record their ideas on intelligence; play games and solve puzzles to learn about algorithms (Figure 3); and talk to an

animated chatterbot to learn why some questions that are easy for humans to answer are difficult for machines.

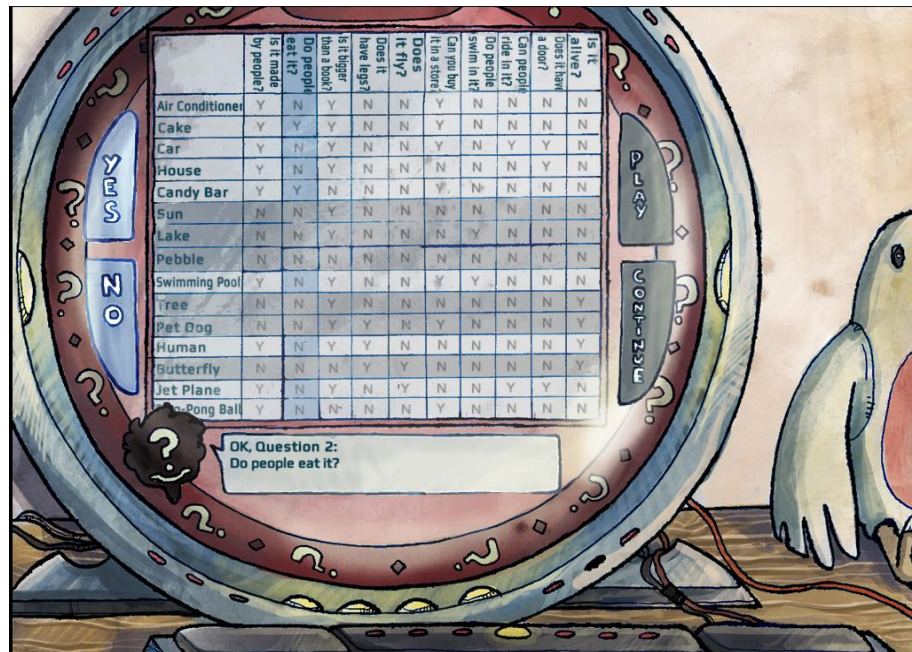


Figure 3: Screenshot of a game exploring the inner workings of 20 Questions from Rio's Brain learning adventure.

- **Trapped in Time:** Sadina and her friends are trapped in a cave below a spooky house. In the cave users discover a time machine that will help them escape, but only after they help the time machine by traveling into the past and fixing some of the problems it has accidentally created. Their travels include visiting Chicago in 1893 to help the mayor choose between Tesla's and Edison's plans for electrifying the World's Fair. Later they travel to 1970 and visit Mission Control in Houston to help save the Apollo 13 astronauts. Finally, they return to the present to apply what they have learned about engineering design and escape from the cave.
- **Catalina's Revenge:** Catalina and Rick (two *Talk to Me* characters) are in a social media feud. Using a cell phone as an interface, users learn about ethics to help a third character figure out how to be a good friend. This leads to exploring the parallels between personal and professional ethics. The adventure ends with a case study in which the users help a biomedical engineer make ethical decisions in her research.

Time Tilter Novel

In *Time Tilter*, fifteen-year-old Singer joins a band of displaced teens in the Time Tilter, a futuristic gaming site created by the mysterious Collusia company. Trapped in the Time Tilter, Singer and her team become the unwilling subjects of Collusia's dangerous research on the limits of human perception. Under the influence of a new and

proprietary chemical called the superzeitgeber, the team loses all sense of time—while other senses become mysteriously enhanced.

In order to escape, they'll have to find out why they're here, figure out how to tap into their new super powers of perception, and fight their way out of a world where you can't always be sure of what's real—and who you can trust. Key plot elements tie into bioengineering.



Figure 4: Screenshot of the Collusia website.

Time Tilter Learning Adventure

Early in the *Time Tilter* novel, readers learn that the fictional Collusia company has a real website (www.Collusia.com) that they can explore (Figure 4). Users can read Collusia news stories, browse employee profiles, and watch a Time Tilter promotional video. Later in the novel, a password is revealed to readers that allows them to access a secret rebel organization called ThirdEye (Figure 5). ThirdEye has hacked into and maintains a hidden presence within the Collusia site. Once in the site, users learn their mission: designing a biosuit that will help them foil Collusia's plans for world destruction. To prepare them for this mission, users learn about engineering materials and design by watching videos produced by the rebels. They also work through case studies of failed biosuits by exploring blueprints, audio logs, new stories, and other items related to each case. From these clues the users can then solve the mystery of why each of Collusia's prototype biosuits failed--information that will be vital to completing their mission.

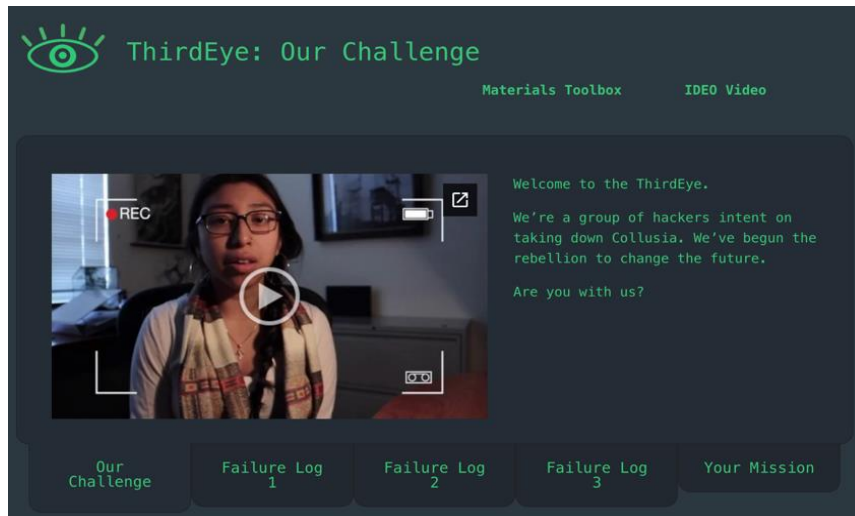


Figure 5: Screenshot of the ThirdEye rebel website.

Assessing Effectiveness

The *Talk to Me* novel and learning adventures were created first and have been implemented in a wide range of formal and informal educational settings—including afterschool programs, summer programs, STEM classes, integrated reading classes, and more.

Surveys show that about 90% of students liked both the novel and the learning adventures to some degree. Girls were significantly more likely to enthusiastically engage with the novel than boys. From matching pre/post surveys, it was found that after using *Talk to Me*:

- 33% increased agreement with “Engineers design things to help people”
- 36% increased agreement with “If I wanted to, I could be an engineer”
- 31% increased agreement with “I enjoy learning about engineering”

No significant differences were found between boys and girls, but students who started out with negative views experienced much greater increases.

It was found that educators who used *Talk to Me* reported the following:

- Students were highly engaged with the stories at the heart of all *Talk to Me* components. This was particularly true for special education students;
- *Talk to Me* expanded both educator and student perceptions about engineering;
- *Talk to Me* made educators feel more confident about open-ended questions and idea-centered resources, improved content knowledge, and engaged students of all ability levels.

A more detailed analysis on the impact of *Talk to Me* in developing STEM identity and learning can be found [here](#).

(<https://www.asee.org/public/conferences/106/papers/21208/view>)



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Finding STEAM Pedagogies in Forest Schools

By Tracey Hunter-Doniger



Introduction

Effective education requires constant reassessment and adjustment of multiple elements (Dewey, 1956). Recently, there has been a push in the United States for more STEM (science, technology, engineering and math) in education (Beal, 2013). STEM concepts are vital, but the positive effects of STEM can be amplified if an A is added for the arts. A STEAM approach to learning can have positive impacts on students' education in early childhood, elementary school, arts education, and in the teaching field in general. The arts provide a component necessary to pique student interest in subjects like science, technology, engineering, and math and thus, STEM becomes STEAM (Hunter-Doniger & Sydow, 2016). The traditional educational structure tends to isolate disciplines; most curriculum designs in the United States teach disciplines exclusively in separation or in silos (Eger, 2013). However, the interest in STEAM instruction has initiated a new revitalization in education. STEAM pedagogies unite disciplines and break down the silos to create learning environments that encompass all subject areas within the curriculum. STEAM allows for content and time to be fluid rather than rigid. Instead of students learning separate disciplines without recognizing how they intersect, STEAM allows content areas to work together to create something

inspirational (Hunter-Doniger, 2016). STEAM pedagogies can take many forms in practice and can be applied within the classroom walls and beyond.

Forest Schools and Forest Kindergartens from Europe take an approach to learning that unintentionally embraces STEAM pedagogies. Forest Schools, much like STEAM curriculums, focus on interdisciplinary and inquiry-based learning. Educators play a facilitative role to promote student-directed learning and autonomy, while providing nonjudgmental and constructive feedback (Madden et al., 2013). This article discusses the findings from an investigation of Forest Schools in Germany and the Netherlands. Nine different schools in Europe were examined over a month-long period with a lens particularly focused on STEAM pedagogies. Researchers found that while STEAM pedagogies were not deliberately used, STEAM was prevalent throughout each school.

STEAM learning was illuminated through three continuing and overlapping contextual factors: 1) creativity, 2) autonomy, and 3) play. This article will define Forest Schools and discuss how these three defining contextual factors are found in the learning environment. Then, direct connections from these contextual factors to STEAM pedagogies will be identified.



Figure 1. An example of tables and chairs in a Forest School.

What are Forest Schools?

Forest Schools are educational programs held predominately, if not always, outdoors. These learning environments are prevalent in European countries like Germany, the Netherlands, Denmark, and Sweden, and they are growing in popularity in England. There are different types of Forest Schools with varying levels of interaction with nature. They range from full days spent out of doors learning in the elements to inclusive

programs where the majority of learning happens inside, but forest learning is a set part of the school curriculum (Wilson, 2012; Schäffer & Kistemann, 2012). Forest Kindergartens are geared towards a full day of exposure to nature, rain or shine, for children between the ages of three to five. These school programs are designed with a child-centered approach to learning that focuses on what the children are interested in, and the teacher acts as a facilitator. While a full day outdoors for older children at the primary and intermediate level is not the norm, some schools embrace nature and forest learning as part of the curriculum and implement an integrated or inclusive model. Inclusive Forest Schools provide a structured curriculum where there is a scheduled time for outdoor exploration. During this time, the learning process is exploratory and encourages creative thinking and problem solving. Although the structure of Forest Schools differs from Forest kindergartens in the amount of time spent in nature, the same contextual factors—creativity, autonomy, and play—are ubiquitous.



Figure 2. A Forest School property with stones in a spiral pattern.

Environments like Forest Schools empower students to construct their understanding and knowledge instead of something being mandated by teachers or standards-driven authority (McCombs, 2012; Gulløv, 2013). Learners who have educational autonomy and are in control of their meaning-making are guided by intrinsic motivation to find and solve problems (Jaquith, 2011; McCombs, 2012). Intrinsic motivation is at the core of a child-centered pedagogy which focuses on children's autonomy, needs, and interests (Gulløv, 2013). Teachers watch and observe

what students are interested in and facilitate learning to allow students to have a say and become active participants in their educational process. This is in contrast to a traditional didactic approach to learning where the teacher lectures the entire class while the students are passive participants in the learning process. In child-centered learning environments where self-directed learning and ambiguity are the norm, learners challenge themselves to take risks (Jaquith, 2011). In Forest Schools, the projects are designed to have useful applications and address real-life situations and issues. Autonomy can be found in purposeful play, and it empowers students in their creative inquiries, which by design makes learning fun.

Learning in a Forest School environment takes place using a model where children are not explicitly taught; instead, the content is experienced, usually through individual discovery or discoveries shared with a group of peers (Vandewalle, 2010; Alcock & Ritchie, 2018). Under the constant pressure of academic standards, play is being replaced by test preparation at elementary schools and even at the kindergarten level (White, 2012; Reade, Hunter, & McMillan, 1999). Parents of young children who aim to give their preschoolers an academic advantage are led to believe that deemphasized play and using flashcards and educational “toys” are the path to success (Elkind, 2008). Often times members of society, including parents, community leaders, and policy makers, believe that play is a waste of time or a filler in between academic learning (Elkind, 2008; Reade et al., 1999). These stakeholders fail to see the bridge between play and learning. When children use their imaginations, the world around them changes to suit their needs (Fisher et al., 2011). Play helps children work out difficult concepts and seek out new and innovative solutions that extend beyond logic (Dewey, 1956). The data from the field notes and interviews from this investigation revealed that STEAM pedagogies in Forest Schools provided possibilities and insights into students’ confidence, engagement, and empowerment.

Discussion: STEAM Connection

The foundation of STEAM is a relationship between disciplines. It requires a give-and-take and an agreed upon respect to collaborate with the aim of enhancing the learning experience and students’ knowledge retention. Given the silos in education today, STEAM is necessary. As teachers adapt to the pedagogy, it may seem forced or artificial at times. It will be difficult at first to get all stakeholders to buy into the STEAM concept. From the Forest Schools observed, the integration and crossover between subject areas happened involuntarily and as part of the exploratory way of learning that a student-centered pedagogical model embraces (Hunter-Doniger, field notes September, 2018). One idea led to another and then another, and through experiments and play, other ideas were brought in as part of the process. Consider how innovation occurs in real life. Does it happen siloed within one field, or is it part of a trial-and-error process that encompasses a variety of disciplines in order to get the best results? In real life, innovation takes creativity, autonomy, and a bit of experimental play.

What can STEAM education take from this study’s findings of Forest Schools? As a pedagogical practice, STEAM allows children to learn subject areas concurrently and with an understanding of how all disciplines are interrelated and how they support one

another. Furthermore, Forest Schools demonstrate that along with transdisciplinarity, creativity, autonomy, and play are necessary. Below are direct correlations between Forest Schools and STEAM as found in this study.

Creativity and STEAM

Although there is no common definition of creativity, creativity is used often associated with the arts (Milbrandt & Milbrandt, 2011; Jaquith, 2011; Zimmerman, 2010). This assumption is inaccurate at best, because the arts do not hold a monopoly on creativity. However, most definitions agree that creativity includes making something new that is useful and original (Abdulla & Cramond, 2017). Creativity can be described as a process, a personal characteristic, or specific to social and cultural contexts relevant to a particular subject or domain (Zimmerman, 2010). An effective educational method should view all children as creative (Zimmerman 2010). Elliott (2015) noted that outdoor education can foster creativity. Children can make meaning of their world through active art making, where they can test and challenge new ideas as they make discoveries (Vygotsky, 1978). The environment is important to the pedagogy because many creative ideas stem from objects found in the forest and the forest itself. Even though it was not in the forefront of the teachers' minds, STEAM pedagogy was evident (Hunter-Doniger, field notes, September 2018). The teachers at these schools used an approach to learning that provided educational opportunities that integrated creativity and divergent thinking into the standards (Hunter-Doniger, field notes, September 2018). A variety of visual and performing arts were utilized to communicate students' understanding of content and respect for nature. Creativity in these schools was abundant, and the children's autonomy fueled that creativity.



Figure 3. Creative work space with tools and items found in nature.

Autonomy and STEAM

Students should not be passive recipients of knowledge. Instead, educators should provide avenues to learning that include arts-infused instruction through collaborative

and active student-centered learning. The autonomy found in the observed Forest Schools is ideal for STEAM pedagogies. The hook of STEAM requires giving children the freedom and autonomy to discover as part of learning. If learning is interesting and relevant to students, they are engaged. Furthermore, if students' thoughts and ideas are considered valuable, they will tend to take ownership of their learning (Jaquith, 2011). Another advantage found in the Forest Schools was the teachers' autonomy, which in turn, provides a stress-free atmosphere for the students (Hunter-Doniger, field notes, September 2018). These teachers did not have to constantly keep students on task, on the same page in a workbook, or make sure their pencils were sharpened. The children were engaged with their learning, and the teachers did not have to expend added energy to get or keep the students on task. Self-directed learning in the classroom for STEAM can be pursued in a carefully designed structure that promotes independence. Rather than being a taskmaster, teachers functioned as facilitators and provide instructional support where needed.



Figure 4. A child constructing a fairy house.

Play and STEAM

Studies have shown that the freedom to play in Forest Schools increases students' interest and knowledge of nature, helps reduce fears of the natural world, and inspires children to become more actively involved in their environment (Ridgers et al., 2012, Hunter-Doniger, 2018). Bringing the play aspect of Forest Schools to STEAM education can help students make learning difficult concepts fun and exploratory rather than a chore. Students can use play to scientifically reason about ideas and test hypotheses on how things work. In one school, the researcher observed children collecting, identifying,

and classifying items found in nature as a part of their play (Hunter-Doniger, field notes, September 25, 2018). These items were then assembled to build fairy houses. The students then role played and pretended to be “fairy real estate agents” as they tried persuasive speeches to convince fairies to buy their house

Conclusion

Profound and unexpected ways of learning take place in Forest Schools through creativity, autonomy, and play. This is similar to STEAM pedagogy. Students and teachers become empowered to explore ideas and opportunities at the intersection of disciplines. When students are given tools, the ingenuity to use them, and the autonomy to explore, they are empowered to expand and try new opportunities and ideas. The Forest Schools observed were able to create almost endless possibilities for learning styles and individual interests by blending subject areas and providing interaction with the natural environment. Creativity, autonomy, and play extended these possibilities further by looking at the robust opportunities that were presented. These opportunities, while unintentional, presented themselves as contextual factors conducive to learning and ideal for STEAM pedagogies. The question facing educators is this: how can these factors be implemented in the classroom for STEAM lessons? Based on this research, it seems that one viable option is to provide several workstations that include investigations where children can feel as though they are researchers. Present a problem and discuss the design process and let students figure things out on their own. The teacher will only facilitate from that point forward through the end of the project. To many educators, this process may sound scary, and it most likely will be noisy, but teachers will see a difference in the independent active learner as opposed to the passive learner, which is ideal for STEAM education.



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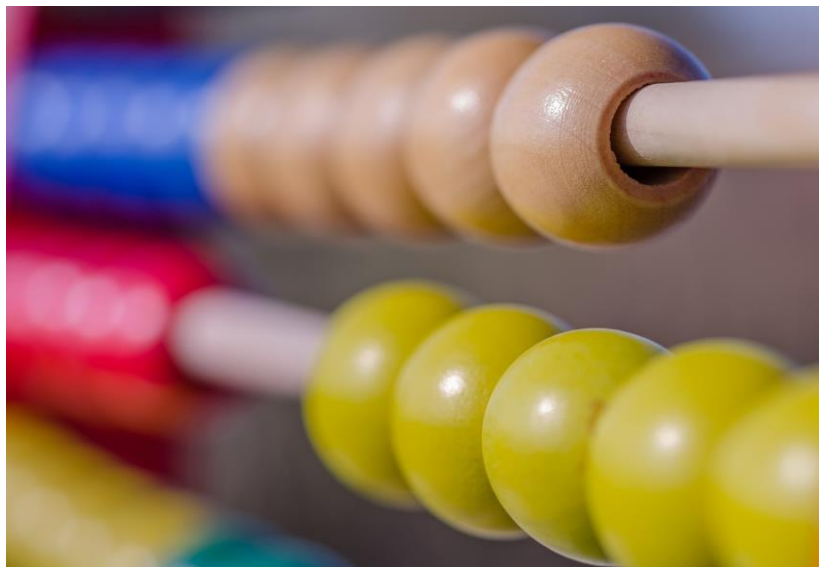
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Fostering Imagination in Mathematics Teaching via Lesson Play Tasks

By Rina Zazkis



“Lesson Play” task – Brief Background

The idea of “Lesson Play” was initially introduced by Zazkis, Liljedahl & Sinclair (2009) in the article “Lesson Plays: Planning teaching vs. teaching planning.” Using the theatrical meaning of the word ‘play’, Lesson Play refers to a task in which teachers are asked to write a script for a lesson, or part of a lesson, presented as a dialogue between a teacher and students. The plays follow a prompt in which the beginning of a dialogue is presented, pointing to a potential problem in learners’ understanding.

Having implemented lesson play tasks in courses for prospective teachers for several years, we accumulated a large amount of data. These data were summarized and analyzed in the book, *Lesson Play in Mathematics Education: A tool for research and professional development* (Zazkis, Sinclair, & Liljedahl, 2013). We discussed a variety of advantages of the task for teachers, for teacher educators and for researchers. For teachers, advantages include the opportunity to examine their personal responses to students’ erroneous perspectives without the need to “think on their feet”, and to develop personal repertoires of general strategies to be used in future improvisations. Obviously, as a tool for professional development, the Lesson Play task shares important features with a variety of other tasks used in teacher education. For example, role-playing tasks also provide an opportunity to imagine personal responses to a variety of situations (e.g., Maheux & Lajoie, 2011). As such, I referred to Lesson Play as imagined—rather than enacted—role-playing (Zazkis & Nejad, 2014), which affords a more thoughtful and pre-planned (rather than “real-time”) response.

For teacher educators, the advantages of Lesson Play included the opportunity to highlight appropriate pedagogical responses and direct teachers’ further attention to

learners. For researchers, implementing lesson plays provided a lens to examine teachers' ideas and discourse via their imagined action and chosen words. Our underlying assumption, based on explicit instructions for teachers, is that a teacher-character's moves in a lesson play reflect its script-writer's personal views. As such, an imagined creative response lays a foundation for implementation in "real teaching".

One of the most popular tasks in teacher education "methods" courses appears to include different variations of writing a lesson plan. In fact, a Lesson Play task was created following my deep dissatisfaction, shared with colleagues, when involving prospective teachers in making lesson plans. The lesson plans written by prospective teachers could properly attend to the (usually) required rubrics of lesson objectives, teacher and student activity, and assessment. These plans could adequately describe the materials to be used in a lesson and projected time allocation for each part or activity. However, the format of lesson plans did not allow for detailed attention to potential student difficulties or errors, or to particular language choices used by teachers. To attend to these essential components in preparing for teaching Lesson Play was created.

Clearly, presenting and resolving complexities in a form of a dialogue is not novel. The idea dates back to Plato (380 CE) and Galileo (1991), and more recently, particularly in relation to mathematics and mathematics education, to Lakatos (1976) and Mason and Watson (2009). Furthermore, focusing on teacher education, textbook authors occasionally present scripted interaction between a teacher and students to introduce a particular instructional approach (e.g., Van de Walle, Folk, Karp, & Bay-Williams, 2011). Researchers create scripted interaction to elicit teachers' discussion, or reflection on the presented scenarios, and study teachers' responses (e.g., Herbst, Chazan, Chen, Chieu, & Weiss, 2011). The particular feature of Lesson Play tasks is that teachers themselves become playwrights.

Lesson Play – some creative responses

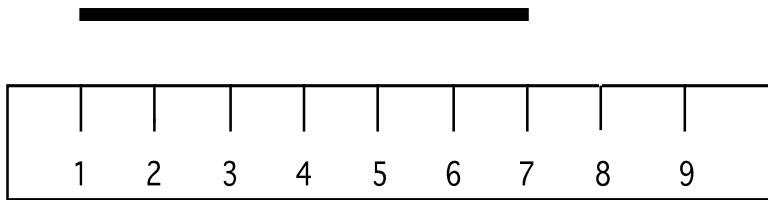
In what follows I introduce several examples of excerpts from lesson plays written by prospective teachers. While all the plays exemplify how the interaction unfolds in the writer's imagination following the prompt, I chose responses that highlight the writer's creativity. That is, the teacher-character's creativity in the imagined dialogue points to the creativity of a prospective teacher-playwright.

Learning to measure with a ruler

Students in your class were asked to measure the length of different objects.
The teacher collected their responses.

Teacher:	Johnny, how long is the stick that you measured
Johnny:	It is ... seven
Teacher:	Seven what?
Johnny:	Seven centimeters
Teacher:	Can you show me how you measured?

(Johnny places the stick next to the ruler as shown below)



Teacher:

This prompt was chosen based on research that described difficulties young learners face when learning to use measuring instruments without a sufficient understanding of what measurement implies (e.g., Kamii, 2006). Note that the same mistaken answer of 7 may result from two different erroneous approaches: attending to the end of the segment and ignoring its beginning or counting the numbers (and separators) appearing underneath the segment.

Excerpt: Starting at 5 or 25

- Teacher: How have you measured?
- Johnny: I started at the beginning (pointing at 1) and it goes up to here (pointing at 7). So this is 7.
- Teacher: So you looked at where the segment started and ended...
- Johnny: Right here...
- Teacher: And what would happen if I move the stick here, or here?
(*The teacher places the stick to start at different points*)
- Johnny: But we have to start at 1.
- Teacher: Just imagine if this was on the floor, and you would need to walk. How many steps would you do from 1 to 7?
(*Johnny mimics the walk and the class counts: "one, two, three, four, five, six"*)
- Johnny: Hey, we stopped 6.
- Teacher: And why is that?
- Johnny: I got confused! I didn't start at zero and count my steps properly.
- Teacher: So if I move the stick here (*aligning the beginning with 5 and end with 11*)
- Johnny: So do not look at where it ends, because it is not 11. Count the steps and there are 6 steps. So, 6 cm.
- Teacher: And if I move the stick to start at 25?
- Mark: The length will not change, no matter where you place the ruler, so if we start at 25, it will get to 31, because $25+6 = 31$.
- Adele: If we measure from 1, it ends on 7, if we measure from 2, it will end at 8, if we measure from 0, it end on 6.

- Sally: It is better to start at zero, so it ends up at 6, and you will know it is 6 cm without counting steps.
- Teacher: Great observation!

This imaginary interaction demonstrates some unrealistic moves, such as Johnny's immediate reaction, "I got confused", or Sally's description of the benefits starting at zero. Nevertheless, the excerpt presents a creative approach of placing the measured object aligned with different starting points on the ruler. Unlike the insistence on the 'rule' of starting measurement from zero found in the scripts of the majority of prospective teachers who responded to this prompt, the writer of the above play introduces the idea that it is possible to start measurement at any point. This idea echoes the approach of a "broken ruler" in teaching measurement, where the beginning of the ruler is intentionally broken and the ruler starts at 2 or 3, rather than zero (Barret et al., 2011). However, the fact that this approach has been explored by researchers previously does not detract from the creativity of the prospective teacher, who suggested aligning the measured object with different starting points on a ruler. Moreover, transforming a mathematical problem—in this case starting measurement at a "big" number of 25—is a creative approach that intends to extend students' understanding and push their imagination beyond work with a physical object.

On car trains

There are 20-25 students in the classroom. They are working on the following problem:

A toy train has 100 cars. The first car is red, the second is blue, the third is yellow, the fourth is red, the fifth is blue and sixth is yellow and so on.

What is the colour of the 80th car?

The teacher is moving through the room observing how the students are progressing. S/he stops and points at one student's work.

T: Why is the 80th car red?

S: Because the 4th car is red, and 80 is a multiple of 4.

This prompt was developed based on prior research on repeating patterns (e.g., Liljedahl, 2004) that demonstrated students' difficulty in perceiving the unit of repeat.

Excerpt: Student train

- Teacher: It seems as though a lot of students seem to have different answers [...] We are going to go through this problem together as a class. We are going to form a train here at the front of the class so we can see exactly what is going on in this problem. Do I have 3 volunteers to start the train?
- Teacher: Luke, you are the first car in our train. What colour are you?
- Luke: Red
- Teacher: Olivia, you are the second car in our train, what colour are you?
- Olivia: Blue

- Teacher: And Michael, you are the third car in our train. What colour are you?
- Michael: Yellow
- [Students continue to come up to be part of the train. Ms. Tooney asks them what colour they will be if they follow the sequence. When Monica comes up she is the 20th car in the train.]*
- Teacher: Monica, you are number 20, and what colour are you?
- Monica: Well, I thought I was Red because 20 is a multiple of 4, but according to the sequence of colours I am Blue.
- Luke: Ms. Tooney, I think I know what Monica is doing. She is counting by fours instead of threes. There are only three colours in the sequence so you should be looking for multiples of three and not four.
- Teacher: Can you explain a little bit more Luke? [...]

We consider this excerpt as an instance of teacher-character directed pedagogical originality in the implementation of a student-train. In most scripts the pattern was explored either with coloured manipulatives or by writing out the pattern of colours. The idea of implementing a student-train accomplishes the task of building a pattern, but also creatively and actively engages the students in solving the problem.

Conclusion

Watson and Mason (2007) suggested that “the fundamental issue in working with teachers is to resonate with their experience so that they can *imagine* [my italics] themselves ‘doing something’ in their own situation” (p. 208). In accord with this view, Lesson Play tasks provide an opportunity for prospective teachers to imagine, and consequently to demonstrate creative approaches.

Furthermore, plays written by teachers served as a springboard for follow up discussions, which attended to both mathematical and pedagogical issues that emerged in the scripts. In these discussions, a teacher-educator presents chosen excerpts (anonymously) and invites comments from the prospective teachers. This exposes prospective teachers to the creative approaches of their peers, and as such extends their personal repertoire of instructional tools. Extending personal imagination fosters teachers’ abilities to extend students’ imaginations.



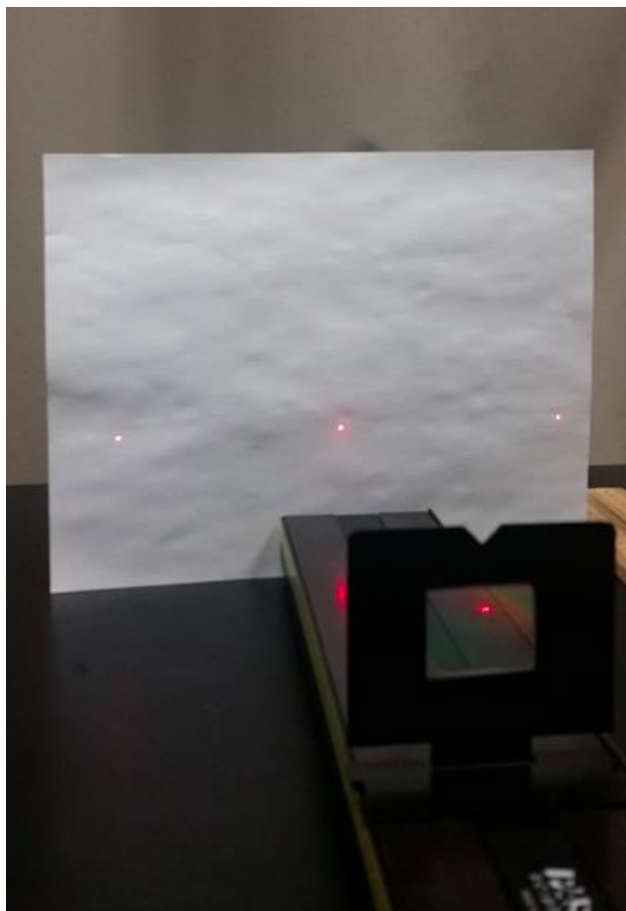
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Light and Color in a Physics and the Arts Course

By Marta L. Dark



Diffraction pattern from a diffraction grating shows the central bright spot and the first order maxima to the left and right of the central spot.

Introduction

All Spelman College students are required to take one natural science course as part of the general education core. *Physics and the Arts* is a course offered by the Department of Physics to students majoring in Arts and Humanities that satisfies this requirement. Currently, the course has five contact hours: three one-hour lecture sessions and a two-hour lab per week. The course is described in a previously published paper (Dark & Hylton, 2018), and its main goal is to create awareness and foster interest in Physics for non-science majors. This article discusses the course activities designed to explore the characteristics of light and color.

Topics related to light and color are integral parts of both physics and arts courses. The first module lasts approximately 4 or 5 weeks and covers the historical

evolution of the scientific understanding of light as a physical phenomenon as well as the unique ways in which painters have portrayed light over the centuries.

Based on Empedocles's theory of primordial substances, ancient Greeks thought that light was both made of the element fire and something that emanated from the eye (Pullman, 1998; Wong & Kwen, 2005). The course describes ancient Greek ideas about light, followed by the contributions of Ibn al-Haytham (also Latinized as Al-Hazen), a mathematician and physicist whose book on optics was written sometime between 1011 and 1020. Al-Hazen's book was translated into Latin towards the end of the 12th century, and his work in physical optics greatly influenced European natural philosophers since the beginning of the 13th century. He is recognized as the first to propose that vision was caused by light reflecting from objects to the eye, in opposition to the prevailing hypothesis that light emanated from the eye itself (Smith & Mark, 2004).

In parallel with the analysis of the evolving scientific understanding of light, the course explores artists' techniques in presenting light in their paintings. For example, in medieval paintings, bright gold paint is used to emphasize surroundings and show religious intent, as in the bright halos representing the holiness of figures in paintings, such as "Pentecost" by Giotto di Bondone. During the Renaissance, Leonardo da Vinci was the first to study light from both scientific and artistic approaches. The use of light and shadow was a hallmark of his technique, leading to an increased realism and perspective in painting. The course also discusses the changes in technique shown in Impressionist paintings by Monet, Degas, and others, particularly short brush strokes, touches of juxtaposed colors, and the vivid colors of synthetic pigments. For example, Monet's "Haystacks" series captures the same subject under the effects of light at different times of day, across the seasons, and in different types of weather. Also, Monet's "Waterloo Bridge" series uses exquisite combinations to portray the effects of drifting mist and fog on the Thames River while conveying a dynamic environment based on sensations of light and color.

Although the ongoing discussions of the artworks are not necessarily comprehensive, they do however keep students engaged in the discussion of physics concepts. The module about light and color emphasizes a perceived connection between arts and science throughout history as developed by Shlain (2007). The author outlined that the evolving scientific conceptual understanding of light changed painting techniques. At the same time, the reciprocal is also plausible: Art may have developed the cultural thinking to push further progress in Physics. Despite the lack of strong historical evidence, Shlain illustrates his framework using, for example, the works of both the post-Renaissance painter Giovanni Francesco Grimaldi and the mathematician Francesco Maria Grimaldi, who were born in Bologna, Italy, twelve years apart. The latter wrote *Physico-Mathesis De Lumine, Coloribus, et Iride*, which was published posthumously in 1666. The painter Grimaldi noted the fringes seen in shadows surrounding an opaque object, whereas the natural philosopher Grimaldi proposed a mode of transmission of light that was different than the prevalent notion of a linear flow (Shlain, 2007). Experiments described in *De Lumine* led to the discovery of the diffraction of light and its wavelike behavior, which was proposed by Huygens in 1678.

The book also influenced another important historical breakthrough: In 1704, Sir Isaac Newton published *Opticks, or A Treatise of the Reflexions, Refractions, Inflexions and Colours of Light* where light is conceived of as being made of “corpuscles” or particles (Boyer, 1968).

The Lab

In addition to the concepts discussed in the class, students investigate related physical phenomena in the laboratory. The physics labs at Spelman are designed to be open ended. About fifteen years ago, the Physics Department decided to move away from labs that were a weekly scientific task, described by a “cookbook” list of steps. The main goals of the new approach are the promotion of scientific thinking and fostering students’ scientific skills. This change occurred in both tracks of introductory courses: the courses for physics, math, and chemistry majors as well as the algebra-based course for biology and pre-health majors. The *Physics and the Arts* syllabus was developed after these changes to the introductory sequence went into effect. In addition to developing open-ended labs, activities that emphasize connections between physical phenomena and artistic techniques and ideas were also implemented by starting with the study of the physical properties of a phenomenon and then examining how that phenomenon relates to an aspect of artistry.

The first lab investigates aspects of light and color. Students carry out activities over a period of several weeks in order to answer the four questions presented below. Instructors help students familiarize themselves with the available equipment and laboratory safety. At times, instructors must review some mathematical concepts with students. For example, trigonometry is an integral part of the lab on light and color. Arts and humanities majors are generally unfamiliar with lab equipment, and they need repeated reminders about laboratory safety, especially when using lasers. Once the students are acclimated to the lab, they design their own procedure and carry it out. The first question is “Can light be modeled as a wave?” To begin this study, water waves are explored by using ripple tanks or videos. This video demonstrates the [Key Characteristics of Waves](http://goo.gl/YRncwC) (goo.gl/YRncwC). Although students are familiar with water waves, they are typically unacquainted with the concept of wave diffraction. After observing water waves passing through openings in a barrier, they shoot a beam of laser light through slits of a diffraction grating. In the Physics 102 course, transparent transmission-diffraction gratings are used. Because they are etched with thin, closely spaced lines, students expect to see a thin slit of light or only one spot of light, the location of which follows a straight line from the laser aperture, through the grating, and onto the screen. Most students seem quite surprised by the multiple bright spots (maxima) (see Figure 1). This unexpected experimental outcome is connected with the earlier observations of water wave diffraction, which helps them flesh out the new concept. After confirming the wave behavior displayed by light, students move to the next investigation, “What does color represent in light?”

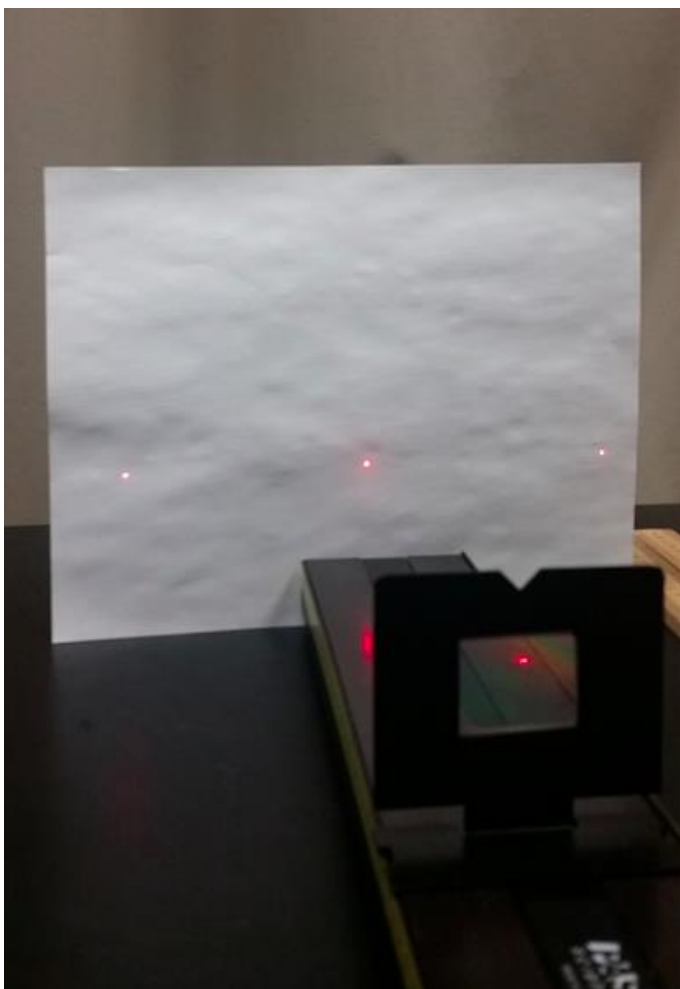


Figure 1. Diffraction pattern from a diffraction grating shows the central bright spot and the first order maxima to the left and right of the central spot. Higher order maxima are outside the view of the image.

Students investigate the pattern produced by another light beam of a different color as it passes through the same diffraction grating. Students recognize a similar pattern of multiple bright spots of light, but the spacing between maxima has changed. At this point, a quantitative study is carried out. They identify the maxima of increasing order and calculate the wavelength, λ , using the grating equation

$$d \sin \vartheta_m = m \lambda.$$

The diffracted light displays maxima of increasing order m at angles ϑ_m , and d is the spacing between the lines on the grating.

Due to the lack of a strong background in math, instructors must take time to work individually with the lab groups on the geometry and trigonometry concepts required to solve this challenge. Students were asked to draw a schematic of the situation before attempting any analysis. The schematic helps them visualize the right triangle involved and determine the needed measurements of distances and angles (see

Figure 2). For a first-order maximum, the measured angle is ϑ_1 , the angle between the path A and path B shown in Figure 2. Path A is the direct path of the laser light from the spot on the grating to the central maximum ($m=0$). Path B is the line of the laser beam which connects the laser spot on the grating to the first-order maximum ($m=1$). Each lab group is asked to measure the wavelengths for two different lasers that are available for this experiment. At the end of the activity, the groups come together and compare their findings, which support the idea that color is how our visual system perceives the wavelength of light.

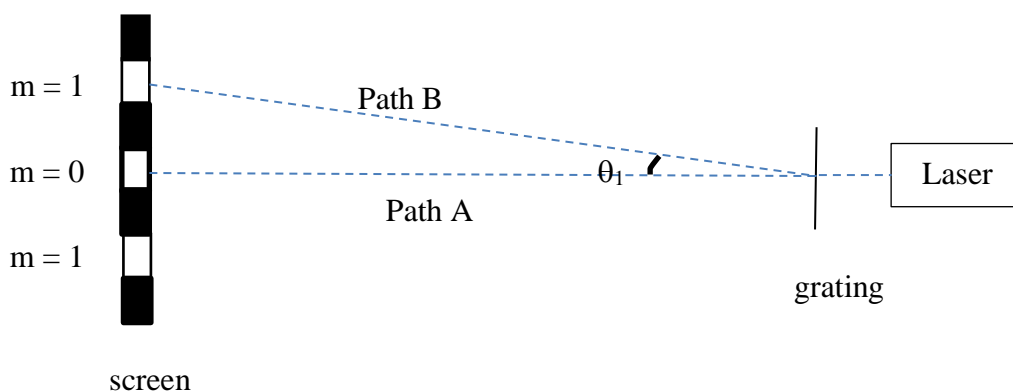


Figure 2. The right triangle used in analysis of the diffraction pattern formed on a screen shows the angle ϑ_m for the first order ($m=1$) maxima. The white rectangles represent location of bright spots in the pattern. Path A is the line the beam makes from the grating to the central bright spot ($m=0$). Path B is the line the beam makes from the grating to the first order maxima.

The third question, “Can light have more than one color at the same time?” has students work with spectrometers. Spectrometers are instruments that, like glass prisms, separate a light from a source into its constituent colors, resulting in a spectrum of the light source. First used is a simple handheld Vernier SpectroVis Plus spectrometer, which contains a grating inside and allows the viewer to see the light spectrum. This spectrophotometer is a plug-and-play instrument which works with existing data collection and analysis Vernier LoggerPro software that produces a digital spectrum for various light sources. After comparing the spectra of different sources, students recognize that light sources can be monochromatic, composed of several discrete colors, or a continuum of all visible wavelengths.

Lastly, students consider other features of light. In this final activity, students consider the brightness of light, a characteristic they can measure easily with the spectrophotometer previously described or a light meter that is compatible with the same software. Groups investigate how brightness changes as they move the sensor away from a light source. They find that different types of light sources show the same

decrease in brightness with increasing distance. Once the lab groups have completed these studies, they use what they have learned to investigate lighting and artwork.

One example of a question they might investigate is, “What are the ideal viewing settings for art with different types of paint?” The groups might look at sunlight versus artificial light or illumination and brightness level for art with different types of paint. The lab groups design an experiment to support their answer to the question. They detail what supplies and equipment are needed and how they will procure the artwork they will study. The groups prepare a detailed plan which discusses the experimental design, specifically what they will measure and how they will measure it. They propose what analysis they will carry out and how they will connect the data and analyses to answer the question.

Final Thoughts

At times, it can be a challenge to keep the interest of Arts and Humanities majors in a general-education core class in Physics. We find it crucial to make frequent connections between the arts and the sciences. Students study scientific phenomena as well as the history of scientific developments. Scientific skill building is emphasized by requiring students to develop their own scientific questions and experimental methods to investigate physical phenomena such as different properties of light. Students who complete this course better understand Physics principles and recognize how those principles are relevant to the Arts.



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Linking the Arts with Science: One of the Most Innovative Models in Education

By Dina Izadi



3D illustration through origami and cutting the paper (ADIB workshops)

What motivates our young generation to learn science is a puzzle and researchers are trying to find the best models in education. In universities and high schools, aged students often have conceptual difficulties in understanding and learning basic sciences, so researchers' attitudes in developing learning outcomes is the first critical step in education (Izadi et al., 2017; Blumberg, 2014). Educators should try to make science more approachable and linking the arts with basic studies in sciences is one of the most attractive models used to solve these issues. We are aware that the key to long-term growth and technological progress depends on developing new types of research and skills for productivity. For this reason, it is urgent to develop creative and critical thinking in students, the ability to use new information on their own, and to construct knowledge on their own (Michellini, 2004).

A growing number of modern high school and college teachers have already realized the importance of moving from a passive to an active-learning environment in order to motivate students. However, many teachers have expressed a need for support in implementing active and engaging learning pedagogies in the classrooms: designing and implementing activities to be used inside and outside of the classroom, as well as choosing pedagogically effective activities relevant to their science curriculum from the

plethora of activities produced by other educators (Izadi & Bolotin, 2004). Artistic creation as a form of active-learning strategy can help students master and transfer scientific concepts by using imagination and creativity. This can inspire them to design their own models such as building toys in an educational framework for expressing ideas on observed phenomena (Izadi, 2017, 2015).

Students in our institutes (**AYIMI** <http://www.ayimi.org> & **ADIB** <http://adib.ayimi.org>) have a lot of freedom to explore in any direction of interest they want. While this approach may seem more difficult logistically or pedagogically in a traditional system, a large fraction of students are prepared to study and are more engaged in learning when given the freedom to pursue their interests (such as participating in different national and international activities—see a list of those international competitions at the end of the article). Solving open-ended problems in basic sciences through their own models, imaginations, illustrations and learning analog skills in conceptual drawing and prototyping, helps students to learn even more difficult subjects that can be part of new technologies in the future (Izadi & Ahari, 2011).

We have found a place for arts in science education in a manner that considers the culture of each community. The main goal of Art in Science Education (ASE) is to give students the opportunity to express their thoughts and feelings in the context of their different cultures and to understand science through the lens of their creative activity in arts (Izadi, 2017). For example, our students are asked to find the influence of Iranian culture in ancient monuments in several cities in Iran and make a comparison with modern forms of art and architecture. They explore the science behind these monuments. For example: *Pasargad*—a palace in Thakhte-Jamshid with incredible high columned halls in the oldest imperial capital city of the world (built by Cyrus the Great (r.559-530) following a military victory; *Choga Zanbil*—a portable water treatment system in Zigorat, built over 3000 years ago and involving a network of canals based on scientific principles (it measures a height of 62m and a length of 105.2 m for each side of the first floor); ancient Persian desert architecture with a wind catcher, which functions as a solar chimney.

In our institutes, students in several categories are asked to participate in several artistic/scientific programs that follow an active-learning by innovation in teaching (ALIT) model (Izadi & Bolotin, 2014). This collaboration between teachers and students requires connecting knowledge and imagination to find different approaches in solving problems.

The ORIGA-SCIE Festival

The art of origami, often associated with Japanese culture, begins with a flat sheet of paper and ends with a sculpture through sophisticated and imaginative techniques. With some modification, the art of origami can be used as a stimulus for the learning process and deep understanding of scientific concepts in Physics, Chemistry, Biology and Mathematics. Origami in Science (ORIGA-SCIE) is one of our festivals for students in two different categories: ages 10-15 and 14-19. They are asked to build their own models using an A3 or smaller sheet paper and investigate some scientific phenomena and

measure the most important parameters in solving the proposed problems using these models.

Design And Construction Of A Rocket Or A Paper Bird

*According to the rules of this section, the use of paper A3 size or smaller without any adhesive is allowed.

1. The scores of this structure consist of several parts:
2. Art used in the construction of a rocket or a paper bird
3. Designing the mechanical shooter
4. Calculating the maximum distance traveled by the paper structure
5. Investigating the factors affecting the distance traveled by the structure and displaying them in a table
6. Optimizing the paper structure to access the highest range for launching and studying the factors affecting the speed of this structure.

Design and Construction of a Paper Bridge

According to the rules of this section, the use of paper A3 size or smaller is allowed. The use of any adhesive or an additional device in the construction of the bridge will result in a deduction.

The scores of this structure consist of several parts:

1. Art used in the construction of paper structures
2. Calculating the maximum tolerated load by Paper Bridge (**Figure 1**)



Figure 1: A simple model of a Paper Bridge

ARTLAND/ BIOLAND /CHEMOLAND Workshops

In these workshops, junior students learn science through illustration and imagination. Supporting their science education, students are asked to reveal their dreams through painting, sculpting or photography. Students demonstrate scientific experiments and prepare 3D illustrations and imaginative sketches with origami or *papier mache* (see **Figure 2 a/b**).

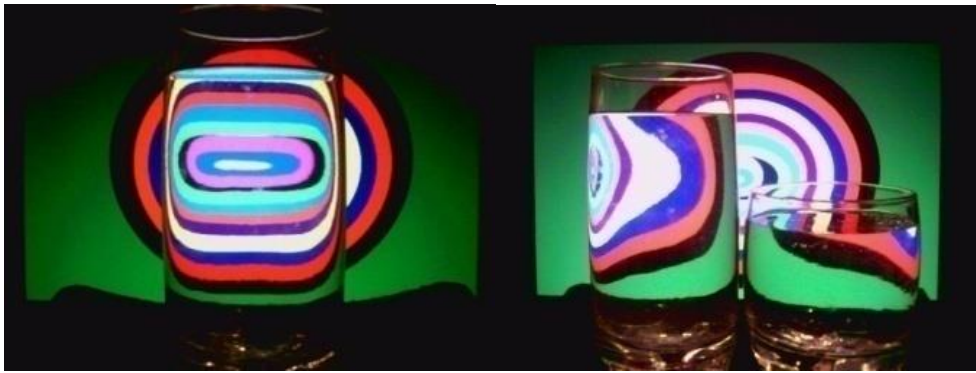


Figure 2(a): Making beautiful lens

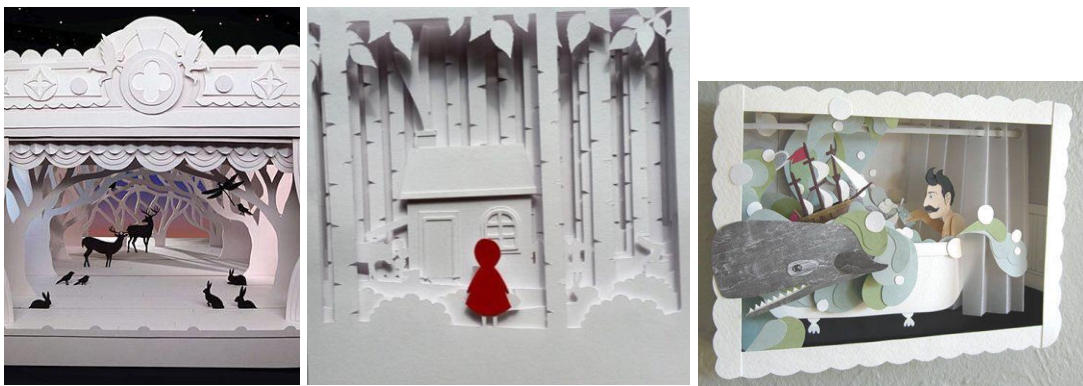


Figure 2(b): 3D illustration and imagination which is built by origami and cutting the paper (ADIB workshops)

Designing and building toys such as a kaleidoscope with the container holding the objects can help students to express their ideas on observed phenomena and compare them as the starting point in building their scientific knowledge. The source factor of the patterns must be fully characterized, which is produced in a random manner, and not just a few fixed images (**Figure 3**).



Figure 3: A photo of a random pattern by the kaleidoscope in our workshop

Conclusion

It would be great to extend and strengthen our community in these artistic-cultural-scientific programs and consider that science alone cannot solve problems and that arts also help to find solutions.



Dr. Dina Izadi is a researcher & Director of Ariaian Young Innovative Minds Institute, (AYIMI) and the ADIB Science & Technology Institute. She is an IOC member of the following international tournaments in basic Sciences: IYPT (www.iypt.org), IYNT (www.iynt.org), IPT (<https://iptnet.info>), ICYS (<http://metal.elte.hu/~icys>), IJSO (<http://www.ijsoweb.org>), IChTo (<http://ichto.org/en/reg-2018>) and an IUPAP WG5 Member (<http://iupap.org>). Email: info@ayimi.org, dina_idus@yahoo.com

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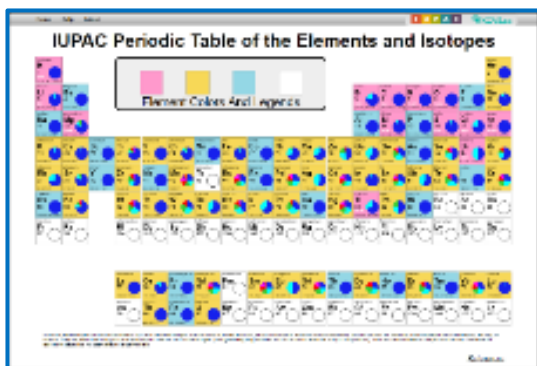
Meet our Partner: The King's Center for Visualization in Science



Have you heard about The King's Centre for Visualization in Science (www.kcvs.ca)? Based at the King's University in Edmonton, an interdisciplinary team of undergraduate research students and faculty directors equips diverse publics to understand phenomena in our world that, by their very nature, are difficult to truly "see" and understand because they are too distant (astronomy), too small (the nano-world), too abstract or too far outside of daily experience (forces or quantum ideas), or too complex (climate science). Its impact is playing out on personal computers and mobile devices across Canada and around the world. Well over a half million visitors from 100 countries used interactive KCVS simulations and learning resources this year; and that number has tripled in 3 years.

Based on a core philosophy that there is no such thing as an undefined public needing to be served by science, KCVS scientists start by understanding their diverse publics and then tailor communication strategies and tools to meet each one's needs for scientific understanding. Those needs range from nurturing curiosity in adults to establishing robust mental models in children, from supporting teachers and scientists in building public understanding within their spheres of influence to helping all these groups see how powerful visualization tools can open our imaginations to address local and global challenges.

Here is a sampler of the interactive resources you may find helpful in your teaching and to support your science communication and outreach activities outside of the classroom.

The image shows a screenshot of the IUPAC Periodic Table of the Elements and Isotopes. The table is color-coded by groups, with a legend at the top left indicating 'Please use Colors And Isotopes'. Each element cell contains its symbol, atomic number, and name. The table includes all elements from Hydrogen (1) to Oganesson (118), plus various isotopes listed below the main table.

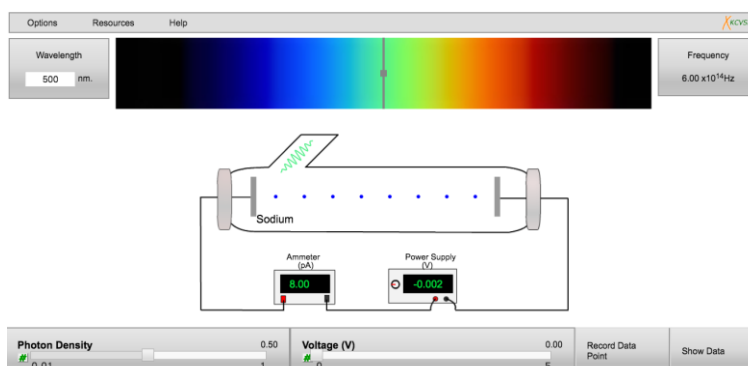
New Year's Day rings in 2019 as the International Year of the Periodic Table. **Did you know** that KCVS has worked with a team of Scientists from the International Union of Pure & Applied Chemistry (IUPAC) to create an interactive electronic version of the new Periodic Table of the Elements and Isotopes, along with Isotopes Matter, a web site with educational resources to help your students understand the importance of isotopes and

to make sense of the intervals that appear instead of single numbers for some elements in the periodic table? IUPAC has recently featured the story of the IPTeI as one of the “IUPAC 100” stories, leading up to the Centenary celebrations of IUPAC in Paris in July 2019 (<https://iupac.org/100/stories/why-isotopes-matter/>).

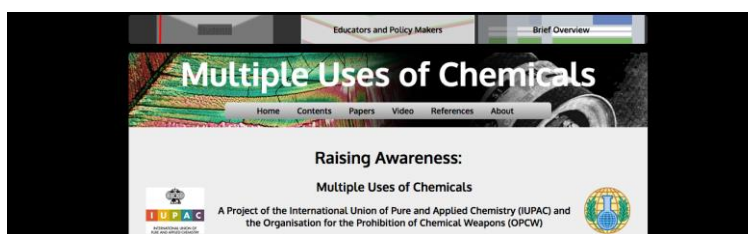
Did you know that skydivers falling to Earth in a dynamic pattern, might be a “good enough” mental model for particles breaking apart and recombining in chemical reactions? Created as part of a SSHRC-funded project on how students in Grade 5 understand the particle nature of matter and the use of scientific models, KCVS has a suite of resources for teaching elementary chemistry.



The 24th UN Climate Summit has just concluded in Katowice, Poland. **Did you know** that KCVS has extensive resources to help your students understand the science of Climate Change, and find accessible and hopeful solutions, such as the [interactive carbon reduction simulation](https://goo.gl/zo3Hhw) (<https://goo.gl/zo3Hhw>). Two sets of comprehensive resources are provided: www.explainingclimatechange.com was created as a legacy resource for general audiences and students between the ages of 17 – 21 for the International Year of Chemistry and has recently been updated. www.VC3Chem.com introduces four central topics to Grade 12 and first-year university chemistry courses through rich contexts related to climate change. This work was featured on the cover of the Journal of Chemical Education in 2018.



Did you know about von Lenard's and Millikan's experiments which provided the experimental understanding of the photoelectric effect and eventual acceptance (albeit reluctant) of Einstein's quantum hypothesis? The KCVS simulation of the photoelectric effect, along with a large set of resources in modern physics and special relativity, actively involves learners in interrogating data and visualizing alternative outcomes rather than prescribing what to think.



Did you know that one of the world's oldest medicinal plants produces a chemical substance that can readily be converted into crystal meth by a chemistry student? KCVS has partnered with the Organization for the Prohibition of Chemical Weapons (OPCW) to create *Multiple Uses of Chemicals*, a set of interactive resources for three target audiences, to help them work through the choices all citizens and students need to make about the ethical and responsible use of chemical substances.

For more information, visit www.kcvs.ca or contact KCVS Centre Director Peter Mahaffy (peter.mahaffy@kingsu.ca)

Meet our Partner: Vintro Entertainment



How Virtual Reality Will Change How We Learn

By Vintro Entertainment's CSO, Lee Brighton.

Education has always evolved in line with technological advances, from teaching originally delivered by parents and their small social groups, to literature-based learning, to today's e-learning. Education has reliably adapted its methodologies to suit societal needs and virtual reality is set to spark the education industry's biggest evolution yet!

So how is Virtual Reality going to help to lead a radical shift in education where cell phones were unable to move the needle?

To answer this question we need to firstly understand what VR is, and its impact.

Virtual Reality is a virtually created alternative reality. VR has an artificially created space to offer the user a complete, immersive experience. In VR the user's external world is removed and replaced by a rich and vibrant virtual simulation. The all-encompassing, visual experiences, coupled with quality sound, invite the user to understand new perspectives, engage in new challenges and interact within powerful and moving experiences. Researchers are finding that the transfer of information to your brain can be likened to how you brain absorbs real experiences—in other words, the experiences in virtual reality feel extremely lifelike and 'real'.

My VR Experience

The impact of VR can be best described through an anecdote of my own personal experience. I, like many other people, show pronounced signs of discomfort when elevated to certain heights—in other words, I am quite afraid of heights. Several weeks ago while attending SIGGRAPH, I jumped in a VR game that challenged me to walk around a room—simple enough. What I didn't realise before going into the experience was that as I moved around, the blocks that I was standing on acted like elevators and while my sensible brain knew full well that I was standing on a sound and strong

concrete floor, my sensors were telling me otherwise. I felt all signs of discomfort that I would feel if I was truly in this situation. Elevated heart rate, anxious and I was no longer confident in walking forward across the walkway. This crunch came for me as I was taken up one more floor and found myself facing a situation where within the game I was now at the 4th floor and I had to walk over a narrow beam that looked like it was no more than 20 cms (10 inch) wide. At this point my mind was racing and with every part of me I wanted to walk over...**But I couldn't move.** The story that the VR was communicating to my brain was overpowering the message, and my fear of heights won. I took the headset off again, reminded of the amazing power that this realm contains.

How VR is a Potent Tool to Disrupt Learning

So here is the reality. VR is a very powerful and immersive tool which will profoundly change the way we play, work and educate. In the education space, VR will offer amazing opportunities to practice learned skills and experience scenarios in a virtual simulated environment.

We'd like to introduce an application that Virtro has been developing this year to disrupt language learning...

Meet [Argotian](http://argotian.com/), the conversational language learning game delivered in VR!
(<http://argotian.com/>)



Virtro's Mission

We are developing Argotian with the intent to make language learning enjoyable and to empower people to be conversationally fluent. We want to give learners the opportunity to practice their speaking and listening skills in an optimised environment—using the smarts of AI and the immersiveness of VR—and be able access this environment wherever they are in the world. We see the social impact of Argotian opening the doors for universal quality learning and lifting the barriers of location and accessibility.

Pilot program launching 2019

Sign up for early access here: www.argotian.com/join

Get involved!

I challenge every educator that reads this to get involved with this new technology. Learn and understand its power to revolutionize the learning landscape for our children and be a part of pushing the technology forward into the mainstream. As leaders you will not hold the next generation of learners back, but rather will empower them and provide them with the tools to change our world for the better.

Stay Connected: Join the CIRCE Email List



Don't miss a thing: **Join the CIRCE email list** (<https://goo.gl/C1rqQu>) to get information on our events, adventures and future publications. Be sure to download a complimentary copy of the Imaginative Education Starter Kit when sign up!



**growing engaged minds with
Imaginative Education (IE)**