At this moment, in Art and Design schools across the country, students are shown all the possible applications of the golden spiral (sometimes referred to as the golden ratio). Art students learn about the golden spiral's historical relevance within art and design while simultaneously being shown how it can assist in creating naturally appealing organic designs in their present work. Meanwhile, in environmental science classrooms, young scientists are taught how the golden ratio pertains to various aspects of natural growth and how they can apply it to better understanding difficult topics such as evolution. Of the parallels that can be drawn between how art and design and environmental science are taught, the golden ratio is only one example of many areas of overlap that more educators in both fields have recently begun to explore by implementing a STEAM (Science Technology Engineering Art and Mathematics) curriculum. Historically, scientific fields have shown a lack of awareness of the importance of art and design. In contrast, having used aspects of science for years (as evident in the application of chemistry, in ceramic arts, etching, and photography), artists and designers are more conscious of the importance of scientific fields. It is essential to rectify the seemingly one-sided relationship between science and art because while it is true that art borrows from science to develop artistic methods, scientific studies, particularly those pertaining to environmental studies, borrow from art as well. By combining art and design and environmental sciences, both fields can benefit as utilizing art and design in environmental sciences can help enhance aspects of the teaching process and environmental studies, specifically those dealing with climatology and pollution. Additionally, by taking an ecocritical approach to analyzing art and its creation, artists can become more aware of the impacts creating certain types of art has on the environment, in addition to noting environmental changes that have been documented through art.

Many of the current issues related to integrating art and design and science stem from an attempt to incorporate them on an educational level; while this recent push for the integration of art into the STEM (science, technology, engineering, mathematics) curriculum has been met with support from educators on both sides, it has also been met with much skepticism. Some educators fear that integrating art and design and environmental science will detract from the importance of both fields independently, making it harder to garner support and funding for each. For STEM teachers, the root of the issue lies in the way educators approach adding art into STEM courses, believing that they do not focus enough attention on fully understanding the STEM subject before advocating an artistic approach. Ernst Eder, a prominent engineering instructor, summarized his reservations about adding aesthetic design in engineering courses by stating, "Before we go overboard, we need a more comprehensive discussion on what is known about engineering and artistic designing, and a more logical approach to teaching and learning" (Eder 2015, 11). Those like Eder worry that by advocating for STEAM curriculums in an age where STEM funding and participation past a high school level are low, adding art to a curriculum may only serve to further distract from STEM educators' needs and draw more students away from necessary but understaffed fields like environmental science.

STEM educators are not the only ones who feel a sense of apprehension; art and design educators worry that the importance of art will be lost in the curriculum if it is only ever seen as a means to progress STEM fields. Many "art education researchers reject instrumental justification for studying the arts as a way to improve student performance in other disciplines" (Bequette and Bequette 2012, 43). Art education experts are concerned that advocating for more inclusion of the arts into STEM fields diminishes the importance of art and design studies where the focus is solely on art. Those in STEM fields have called for a full stop in integration until

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there is more information available on how an interdisciplinary approach will affect the learning process, insisting that "seat-of-the-pants approaches are sorely inadequate in these times" (Eder 2015, 11). However, many art educators are still calling for collaboration. Art teachers and professors assert that ‘the two fields can be of assistance to one another.’ Stating that "art education need not be teleological in order to be of value… Creativity, aesthetic sensibilities and appreciation, higher spatial reasoning skills, sensory awareness, and many other benefits of art have cultural value that are not easily measured" (Bequette and Bequette 2012, 43).

In schools, both environmental science fields and the arts have been neglected. For environmental science, funding and attention came in the form of STEM curriculums. In the early 2000s, the National Science Foundation started promoting "a new breed of comprehensive science education that interfaces with technology and math" (Bequette and Bequette 2012, 43). Contemplating how these fields intersect would eventually lead to the idea of STEM as it is known today. Shortly after, schools began to claim a STEM-focused curriculum, some even promoting themselves as "STEM institutes" in order to receive the grants which were often given to help fund this new teaching style. However, while science courses began to see an increase in funding due to the promotion of STEM curriculums, art and design, courses continued to experience funding cuts. Importance was placed on teaching science, technology, engineering, and mathematics together in a module due to the similarities – "problem-solving, arguing from evidence, and reconciling conflicting views" (Bequette and Bequette 2012, 43). However, even though art and design fields teach similar styles of problem-solving, they were left out of the conversation. This exclusion might result from a lack of art and design instruction within schools where thinking strategies are concerned, teachers opting instead to focus on technical tasks that involve the use of tools instead of teaching conceptual problem-solving. The benefits of conceptual problem-solving is why it is of the utmost importance that,

> The business of art education must include advocating for elevating the prominence of the arts in STEM learning. By highlighting the essential aims of art as a discipline and how the principles that inform art and design can be adapted to present science to the public in an national support. However, the artistic process is not one that science, math, or technology teachers have been prepared to address. Art educators need to be at the table and advocating for their expertise in any discussion of STEM curriculum (Bequette and Bequette 2012, 47).

In recent years, despite the reservations of some art and design and STEM educators, the process of moving to a curriculum that incorporates the conceptual problem-solving of the art studio into a STEM curriculum began to move forward. This new inclusive curriculum was dubbed STEAM (science, technology, engineering, art, mathematics). By approaching STEAM from a problem-based learning perspective, schools have begun to teach in a way that introduces creative problem solving and interdisciplinary studies at a young age, instilling in students the importance of a well-rounded education. While lesson plans for this new curriculum look different for every classroom, educators Irene Plonczak and Susan Zwirn, along with a combination of "preservice and in-service teachers," created lesson plans which cut across disciplinary lines without privileging science or art. This balance is accomplished by having an art teacher and a science teacher expound upon the same lesson pointing out the multiple relevancies of one topic. An example of this interdisciplinary style of lesson plan can be seen in lessons such as drawing images of cells to strengthen their understanding of neuron theory. Without further explanation, one might assume that this particular lesson could only relate to environmental science. However, when following a "crosscutting" lesson plan, students not only learn about cellular structure and neuron theory but learn to pay attention to "issues of scale,

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proportion, and quantity; they recognized patterns, and they identified connections between structure and function" (Plonczak and Zwirn 2015, 60).

Another example of a crosscutting lesson plan is one centered around fractals, specifically a Fibonacci series. From the art and design perspective, students focus on pattern recognition, finding Fibonacci sequences in nature before subsequently drawing what they noted in order to reinforce what might constitute a natural design pattern. A science teacher would then make sure to underscore the role these patterns they have noted in their drawings play in natural phenomena: "specifically how the alignment of leaves in a fern represents the most efficient way to capture sunlight" (Plonczak and Zwirn 2015, 61). This balanced approach to a STEAM curriculum allows for a marriage of fields which allows students to use "scientific and artistic principles to create or examine art and probe scientific ideas deeply" (Plonczak and Zwirn 2015, 62).

The benefits of combining art and design and science do not stop at a high school education level, with many collegiate and professional environmental scientific studies utilizing art as a way to strengthen findings or as a basis on which to build a completely new study. While cross-disciplinary studies are not new, they are now receiving more recognition and seen more and more frequently, especially where the field of environmental science is concerned. This increase in artistically driven studies is likely related to a fundamental drive that is shared by "the scientist and the artist [who] both search for the reality that exists beneath the surface of reality; the artist might describe the scientist's problem solving as inspiration, and both evolve from creativity." As Max Plank said, "the scientist needs an artistically creative imagination" (Plonczak and Zwirn 2015, 58).

A perfect example of what an "artistically creative" environmental scientists looks like is C.S Zerefos. In 2007, Zerefos published a study titled "Atmospheric Effects of Volcanic Eruptions as Seen by Famous Artists and Depicted in Their Paintings," and predictably, this study sampled the works of painters from 1500-1900, which captured the sunset around the time of major volcanic eruptions, aiming to utilize the painting as "proxy information on the aerosol optical depth" (Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4027). Aerosols are particles (solid or liquid) that are suspended in the atmosphere. Anything from volcanic ash to sea salts to factory pollution exemplifies an aerosol. The concentration of aerosols, or aerosol optical depth, is measured on a scale of 0.0 to 1.0, with 0.1 representing a completely clear sky (Voiland 2010). Depending on the concentration of aerosols, cooling effects at the surface may be observed. With talks within the environmental world turning to climate change, it is becoming more common to see discussed "the effects of volcanic eruptions on climate" (Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4027). Because of the curiosity centered around the ways in which volcanic eruptions affect the aerosol optical depth, there were many "volcanic aerosol indices" created, of which the ice core sulfate Index is able to recreate volcanic aerosols from as far back as the 1500s. Zerefos's study seeks to find similar data, specifically, by attempting to find "the aerosol optical depth before, during and after major volcanic eruptions by studying the coloration of the atmosphere in paintings which portrayed sunsets in the period 1500–1900, i.e., when atmospheric observations were scarce and mostly non-existent" (4028).

When choosing which paintings he would analyze, Zerefos first selected artworks that he felt represented sunsets during periods of volcanic inactivity. The second type of painting Zerefos searched for were those which were completed within three years of a major volcanic eruption. Zerefos was able to utilize these paintings as observational data to find aerosol optical depth by analyzing the red/green ratio in the sunsets by calculating "the RGB values measured on the digitized paintings" (Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4028) and the solar zenith angle when applicable. Zerefos notes that the color differentiation in the paintings caused by the age of the paint has no impact on the information he was gathering. "The estimate of the aerosol optical depth was done by converting the R/G measurements on paintings at a given solar zenith angle through the nomogram … to [an] optical depth at 550 nm" (Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4031). Through this study, a high correlation was found between known volcanic activity and the coloration of the paintings (Figure 1), as well as a high correlation between the aerosol optical depth calculated from the painting vs. the estimated depth as estimated by other studies. (Table 1) Based on the results of this study, Zerefos believes that in addition to providing a basis on which to compare present aerosol optical depths to find changes in AOR related to increased air pollution over Europe, this study will pave the way for "more research to be done on environmental information content in art paintings" (Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4033).

However, while Zerefos conducted a thorough study which accounted for many variables within the natural world as well as within the model data, one aspect of the study is still debated; the assumption that the artwork chosen was *aiming* to portray reality, rather than represent an emotion through the use of colors. The fact that Degas' work was among the paintings chosen, highlights the fact that the aesthetic palette of the artist was not fully taken into account when selecting artwork to utilize for this study. In his analysis of Zerefos's study, Gemtou expresses concern for this oversight by further explaining the difference between artistic values and scientific fact stating that "artwork cannot be seen as a source of objective truth about the world, except in cases where it is used to illustrate scientific texts or where there is a clear intention on the part of its creator to give an accurate and consistent representation of reality" (Gemtou 2011, 52). That being said, there are studies that occurred after Zerefos' which that took this aspect of utilizing artwork as observational fact into consideration.

In 2015, Kothe, Maute, and Brewer chose to use documentarian artwork as a source in their study on climate change and how it has affected the Alpine landscape. In their study, the team notes how invaluable a resource art is for being able to visualize the evolution of icy landscapes, stating:

> The role of artist documentarians often intersects that of naturalists, scientists, environmental activists, and explorers. From early alpine and polar expeditions of the late 1700s to current scientific travel, artists have embarked on or been contracted to join expedition teams to provide unique perspectives and revealing imagery (Kothe, Maute, and Brewer 2015, 49).

In 1901-1904 and again from 1910-1912, Edward Adrian Wilson acted as an artist-naturalist for Capt. Robert Falcon Scott's Antarctic expeditions, and though Wilson died, the artwork he created on these journeys has played a vital role in studies of ice physics, the biology of the emperor penguin, and in a world where these regions are melting and changing, Wilson's landscapes are a window into the past which has allowed researchers a baseline on which to evaluate the effects of climate change in the Arctic. Another artist who similarly contributed to the Arctic research was Joseph Bettannier, whose drawings helped support Professor Louis Agassiz's theory that glaciers are not static but rather advance and retreat repeatedly. In more recent years, photography and videography have become the more popular method for measuring climate change in the Arctic, and while some expeditionary artists still prefer taking quick sketches to capture their observations. With more frequency, artists are using new techniques to

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not only capture a landscape in an ecosystem, but to capture it in a way which can impact how those who view their art see climate change. Innovative artists like these show how art can be more than just an observational tool within scientific studies. While the past observational drawings enable scientists to study periods of time which might otherwise be lost to society, more and more art is being used as a tool to "contribute to the study of climate change through observation, documentation, interpretation, creation, and communication" (Kothe, Maute, and Brewer 2015, 54).

This idea of utilizing a synthesis of art and science to create works that will raise public awareness of climate change was the driving force of the Cape Farewell Project, created in 2001 by artist David Buckland. With the Cape Farewell Project, Buckland hoped to one day "develop the production of art founded in scientific research… by exposing artists to the world's climate tipping points" (Giannachi 2012, 125). One such artist involved in the Cape Farewell Project who is utilizing her art to communicate the seriousness of climate change by interpreting data is Anna McKee, who takes "ice core samples from [the] Antarctic Sheet Divide" and creates a "vertical landscape" (Kothe, Maute, and Brewer 2015, 51). This vertical landscape is a mix of ice core data, which reveals the increase in carbon dioxide in the Earth's atmosphere that has occurred since the Industrial Revolution and the shapes that the trapped gases create within the ice. McKee creates aesthetically balanced pieces which communicate a history of climate change in a visually intriguing way by translating the ice core data through the use of collagraphy and etching, using techniques such as chine-collé to create the gas bubble-esque overlay (Figure 2). Another thought-provoking piece that came out of this collaboration between artists and scientists was *Marker 1*. Created by Antony Gormley, *Marker 1* was a humanistic ice statue of imposing size, placed strategically on the "frozen sea of the fjord until it melted … [and] was finally reclaimed by the sea" (Giannachi 2012, 125). *Marker 1* relied less on scientific data to make an impact than the actual changing conditions in the Arctic region, representing "in one image the causes and effects of climate change" (Giannachi 2012, 125). It was projects like Cape Farewell which allowed artists and scientists space to brazenly broach the important conversation of climate change from a new artistic perspective in a way that would be able to communicate it to a larger audience.

It is important to note that an artistic collaboration with scientists is by no means limited to the Cape Farewell Project or other large platforms because "despite their differences in methodology and language, science and art have things in common and reveal possibilities of complementarity, making it possible to produce more comprehensive and successful results" (Gemtou 2011, 52). Therefore, while projects like Cape Farewell and the German collective Artcirolo help to facilitate a creative environment, artists have been working to promote awareness of climate change outside of larger groups as well. This type of art is often dubbed environment art. "Environmental art includes a range of practices that describe or celebrate nature, as well as ecological or politically motivated work that addresses environmental issues" (Jacobson, Seavey, and Mueller 2016, 1). Of the artists who specialize in combining art and science, Nathalie Miebach is perhaps one of the most unique. Visually, Miebach works to combine scientific data "related to ecology, climate change and meteorology" (Miebach 2021) with sculpture (specifically woven sculpture) to create three-dimensional representations of this data while also creating a visual narrative about how humans are affected by climatological changes. Miebach is particularly taken with "the role visual aesthetics play in the translation and understanding of scientific information" (Miebach 2021). Traditionally scientific data is presented in graphs and charts; however, many times, these graphs fall short of effectively communicating the real-world impact of the data on a page. Specifically, in meteorology, the wind, precipitation, pressure, and marine data are not generally represented in a way in which the viewer would understand in a three-dimensional way. However, Miebach's artwork is not just about representing data but about how people who live in these climates are affected by the changes that are happening around them.

A prime example of work that combines meteorological data and the effects that it has on the people who live through it is Miebach's series on Hurricane Sandy, which she aptly named *Sandy Rides*. Of the series, *The Last Ride* (Figure 3) is particularly striking as it uses weather data to create the iconic Star Jet Rollercoaster, which was caught up in Hurricane Sandy and washed into the ocean. The weather and ocean data that have been visually translated is from the 29th to – 30th. The bright pink, yellow, and blue hues of this woven piece at first glance give off a cheery appearance of a rollercoaster that, upon closer inspection, begins to tell a darker story. The reality of just how much climate change will impact coastal residents became clear as Hurricane Sandy tore through New England. In this sculpture, the hurricane's upper airflow is represented by a blue woven dragon, which appears to ride the roller coaster, similarly to how the roller coaster rode the hurricane into the sea. Another piece that approaches the heavy subject of hurricanes with a lighthearted color palette is Miebach's piece on Hurricane Noel. Made from reed, wood, plastic, and weather data, the woven *Hurricane Noel* (Figure 4) sculpture once more captures the powerful nature of the storm in a whimsical manner, with the upper air data represented by wooden beads that evoke images of the abacuses which are given to small children, topped by wind barbs which depict the directional flow. The base of this structure is formed by "weaving a basket, which, like most data graphs, are formed with lines on horizontal and vertical axes" (Hanna 2013, 3205). However, one of the more striking aspects of *Hurricane*

Noel is how well it depicts the structure of a hurricane, the center weave could represent the storm core, with the outer structure not completely centered, representing how storms stack while simultaneously showing how the wind, influenced by pressure gradients wraps around the eye. Looking at Hurricane Noel from this perspective elicits the same feelings one might get from looking at the blueprints of a building, enabled to see the bones of that which people interact with. In essence, Miebach plays with "the dissonance and co-existence between the physic of weather with the theater of human responses as we come to terms with our changing weather" (Miebach 2021).

Though not completed by a singular person, another sculpture which was created based solely around the impact of CO_2 emissions on the environment (specifically, how it is affecting British heritage sites) is the CO_2 morrow project. The sculpture was designed referencing the investigations of Sarah Staniforth, and Omar M. Yaghi., who “developed a molecular sponge that acts as a carbon scrubbing molecule” (Lutyens 2013, 126). The finished sculpture was displayed in Burlington garden during the U.N Climate Change Conference of 2009. The inner lights changing to represent the current CO_2 levels in the atmosphere, “magenta meaning higher CO_2 levels and blue meaning lower” (Lutyens 2013, 129). After the conference, the sculpture came to reside in front Seaton Delaval Hall. Lutyens describes the creation of the “CO_2 Morrow” sculpture, which was based on Dr. Yaghi’s carbon scrubbing molecule, as effective in combing atmospheric data with artistic design to create a monument that successfully communicates the importance of lowering CO_2 emissions and the importance of inter-disciplinary collaboration in the efforts to spread awareness of climate change.

Not all artists choose to communicate the message of climate change through traditional sculptures. Other environmental artists have chosen to take a different approach to portray the

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importance of climate change through the use of interactive art exhibits. It is thought that "interactive art installation exhibitions have the potential to attract large public audiences. Thus, such installations can be significant tools for communicating environmental effects of climate change" (De Bérigny and Faleh 2014, 451). One exhibit which takes this interactive approach to the next level is *Reefs on Edge.* Based on how climate change is affecting the Great Barrier Reef, this installation pulls research from Erika Woolsey's project, which documents the survival rates of young coral. *Reefs on Edge* utilizes various forms of artwork to communicate the message about the importance of conservation efforts. Among these art forms, paintings created by onacloV are used, which represent a reef during spawning periods are utilized. Video installations by artist Ge Wu project traditional healthy reef colors onto sculptures in order to show viewers exactly what a healthy reef looks like before comparing this image of reef vitality with one which is drained of color due to reef destruction, mass bleaching, and ocean acidification. In addition to these more traditional forms of art, *Reefs on Edge* also employs a tangible user interface. Designed using a platform for artists, this tangible user interface allows installation goers to directly see how "rising temperatures and ocean acidification" (De Bérigny and Faleh 2014, 453) by physically controlling and interacting with "tangible bits" (452).

However, while the positive impact of art on the field of science are plentiful, it is important to note just how much of an impact environmental science can have on art through an ecocritical lens can help reframe and bring new meaning to artwork by unearthing previously overlooked ecological issues which were occurring at the time. "For art historians, ecocriticism entails a more probing and pointedly ethical integration of visual analysis, cultural interpretation, and environmental history including aspects of the history of science—than has prevailed in the field" (Braddock 2009, 20). Braddock uses Thomas Eakins William Rush as his example to explain how by looking at this painting from a new perspective, it is possible to note the impact of Philadelphia's growth and industrialization (and the subsequent concerns about sanitary conditions) might have played into Eakins' painting. Specifically, when analyzing this piece, Braddock made sure to point out Philadelphia's environmental issues, especially those which involved the Schuylkill River, which "was so badly tainted by untreated industrial waste and domestic sewage that disease reached scandalous proportions, with hundreds of residents dying annually from typhoid" (Braddock 2009, 26). The environmental aspect of this symbolic painting, when considering the time's dire environmental conditions, places this work of art in a whole new light. This type of ecological awareness can increase the understanding of works of art that were previously thought to be fully understood. Ecological, historical information can help elucidate new levels of understanding. "While an irreducible humanism obviously informs all scholarly inquiry, ecocriticism envisions a more self-critical approach marked by subtler awareness of the environments in which art has unfolded" (Braddock 2009, 27). Considering ecological phenomena in the present tense can help clarify nature photography for what it truly represents.

Though the fields of art and design are often thought to be separate, this separation is in many cases is arbitrary; when the two fields are merged, both fields can be strengthened. Specifically, in education, when art and science are mixed in a cross-disciplinary approach, harder concepts are able to be presented in a way that will increase a student's likelihood to retain the material.

> According to the advocacy group Americans for the Arts, arts education has undeniable benefits for academic performance. It stimulates and develops the imagination and refines cognitive, creative, problem-solving, and critical-thinking skills, adding to overall academic achievement and school success. It has also been proven to help level the "learning field"

> across socio-economic boundaries and nurtures important values, including teamwork, respect for alternative viewpoints, and appreciation and awareness of different cultures and traditions (Plonczak and Zwirn 2015, 58).

Additionally, at more than just an education level (if the artist has stated that their work was intended to represent reality, or if the drawings were created for the specific purpose of documentation), art can be used as a valid source of data in environmental studies and experiments where otherwise there might have been gaps within the data. This type of scientific supplementation is more often seen in climate change studies, where in addition to utilizing art as data, art is also used to raise awareness for climate change in a way that will reach a larger audience. In many ways, art that spreads awareness about climate change is also the art that functions to teach the general public about environmental science in a way. At the same time, they will understand, much like a crosscutting STEAM curriculum would in a schoolhouse. The hope of these artistic and environmental science collaborations being, that "through these actions, artists help people think differently about the lands on which they live and how they can be environmental stewards through their everyday actions. Working together, artists and scientists [can] address global [climate] changes" (Kothe, Maute, and Brewer 2015, 54).

Furthermore, artist-historians who are environmentally conscious can use an ecocritical approach to expand their understanding of both historical and present-day artwork. This evidence therefore supports not only including art in STEM curriculums, but also bringing artists on scientific expeditions, and utilizing art to supplement scientific research. Art and science have always been connected, in reality, “the division between art and science results from arbitrary constructs of formal education” (Jacobson, Seavey, and Mueller 2016, 1). It is this early division which needs to be addressed first in order to truly strengthen both career fields, but change is possible and occurring every day. One day soon, maybe art will have a more permanent and acknowledged part of the scientific community, and more environmental consideration will be given to both past and present artwork. Until then, projects that bring together artist and environmental scientists, like Project Cape Farewell will be instrumental in breaking down the stigmas formed by society in order to allow these groups of people to work together to achieve shared goals such as climate change awareness.

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List of Illustrations

C. S. Zerefos et al.: Past volcanic aerosol optical depths

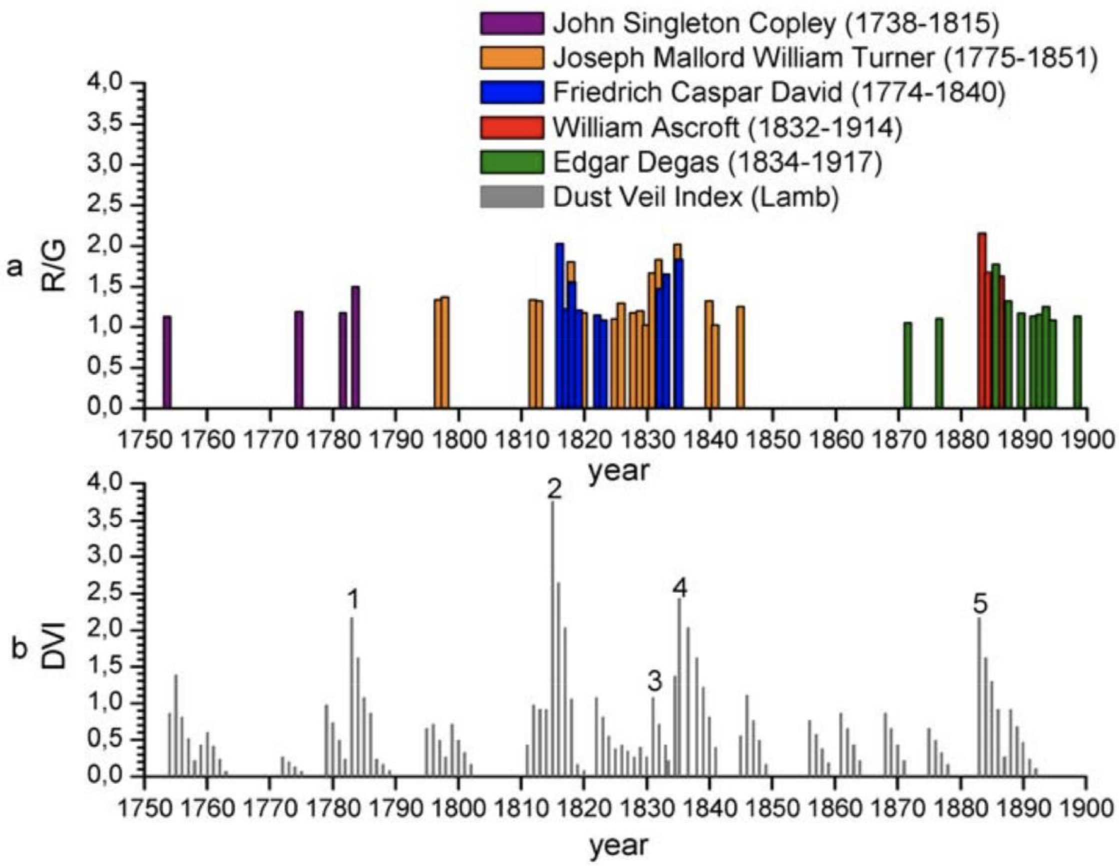

Fig. 1. **(a)** The variation of the chromatic ratio R/G that correspond to paintings of Copley, Turner, David, Ascroft and Degas. **(b)** The Dust Veil Index. The numbered peaks are 1. Laki, 2. Tambora, 3. Babuyan, 4. Coseguina and 5. Krakatau.

(Zerefos, Gerogiannis, Balis, S.C. Zerefos, and Kazantzidis 2007, 4029)

Figure 1

Figure 2. Anna McKee, *Depth Strata V*. 2011. Etching, collography, chine-collé: Image size: 24 x 18 in. (61 x 45.7 cm); paper size: 30 x 22 in (76.2 x 55.9 cm)

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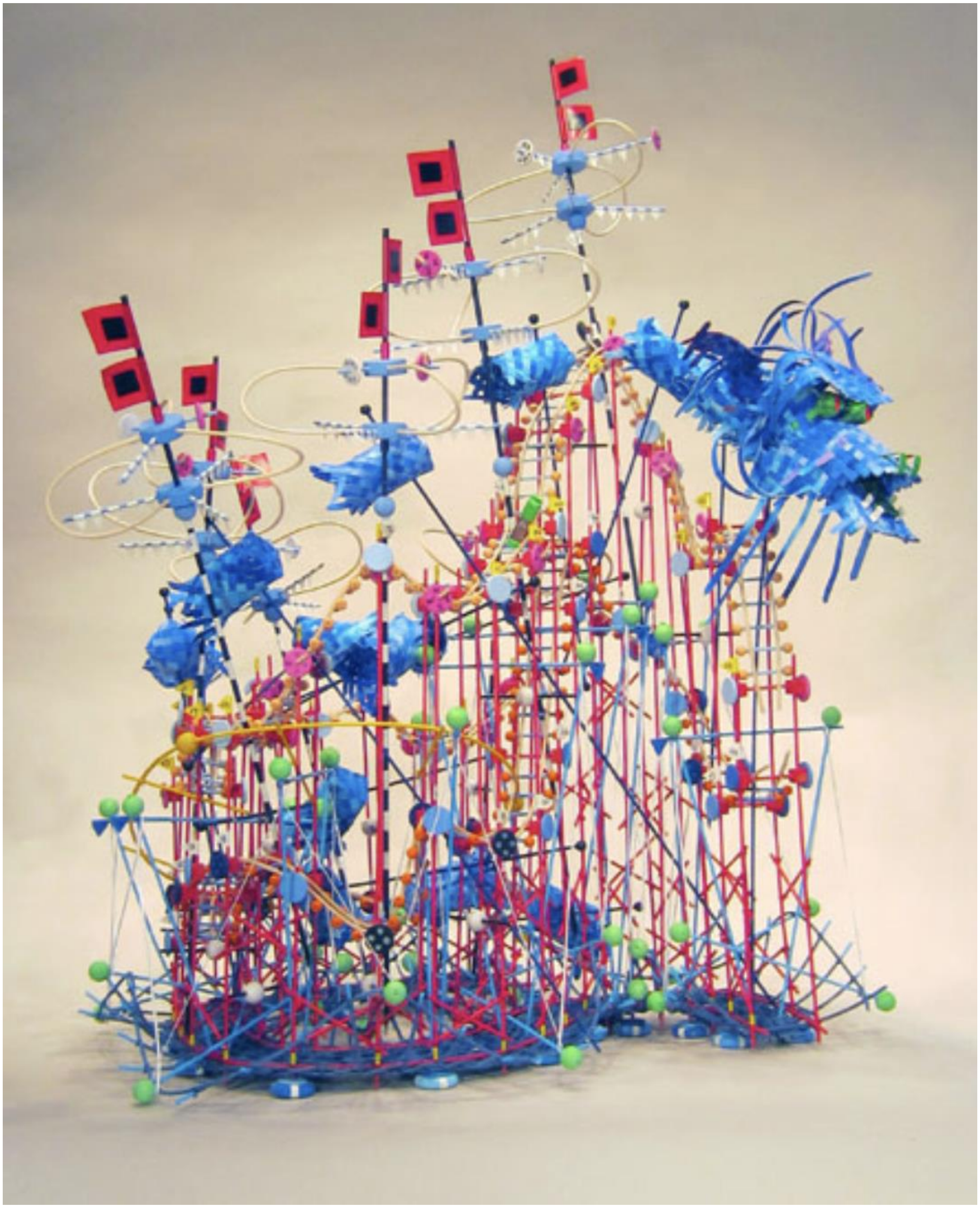

Figure 3. Nathalie Miebach, *The Last Ride.* 2012. Reed, wood, data: 38(h)x31(l)x26(w)

Figure 4. Nathalie Miebach, *Hurricane Noel.* 2010. Reed, wood, plastic, data: 32”x32”x36”

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