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STEM in the Art Museum: Innovative Pedagogies for the 21st-Century University

Edited by Liliana Milkova and Jodi Kovach

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Cover image:
Kazimir Malevich, *The Knife Grinder or Principle of Glittering*, 1912–13. Oil on canvas.
Yale University Art Gallery, Gift of Collection Société Anonyme, 1941.553

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CONTENTS

STEM in the Art Museum: Innovative Pedagogies for the 21st-Century University

Liliana Milkova and Jodi Kovach

Creativity, innovation, and discovery in science and medicine have become more important than ever as humanity faces increasingly destructive and multifaceted crises in the physical and technological realms. Nurturing the mind to think not just critically but also creatively, expansively, outside conventions and expected outcomes, is what universities should aspire to do. In higher education, however, disciplines and divisions of the arts are typically separated from those of the sciences, and yet the most original and generative thinkers are often inspired by both. This volume argues that art can animate the study of science, technology, engineering, and mathematics (STEM) through diversifying classroom routines and defamiliarizing the learning process, providing real-life examples of science's relevance, and cultivating agile, imaginative, and empathetic thinkers with a broad understanding of humanity and history.

The intention behind this volume is dual: we hope that faculty and museum professionals alike will find inspiration and practical guidance in it; we also hope that it will encourage, if not accelerate, the growing relevance of object-based pedagogies and experiential learning in the sciences. Thus, the articles included here explore the utility of museum collections to university-level teaching and research in STEM fields. They expand and deepen the discourse on teaching STEM in the art museum and establish correspondences between the work done at liberal arts colleges with museums on campus and in university settings with highly specialized STEM programs and clinical fields of study. The articles offer a range of perspectives on and approaches to teaching *with*—not strictly or necessarily *about*—art or art history in biology, chemistry, computer science, the geosciences, mathematics, neuroscience, physics, and medicine, and further emphasize the collaborative nature of successful faculty-museum partnerships. Four thematic threads, briefly discussed below, run through the volume, and while we have provisionally identified two or three articles per theme, there are several thematic crossovers in each contribution. Filipowska's coda concludes the volume, weaving, like the other texts, multiple semantic threads. Among them, the coda stresses in particular the seminal role of community among STEM researchers in overcoming existing and perceived disparities in the field, as well as in maintaining a strong sense of connectedness to the world and to our shared humanity.

Developing Essential Skills and Sensibilities for STEM Disciplines and Professions

This thematic thread focuses on activating art's capacity to stimulate reflection, strengthen discipline-specific skills, and enhance thinking dispositions that are hard to quantify but often are even more important for professional success, whether in STEM or the medical field. McMahon and Kovach, Raad and Hurley, and Harris et al. similarly highlight the importance of moving the site of instruction to a new space and of creating the opportunity for students to slow down and engage in individual and collective observations, conversations, and introspection. Raad and Hurley and Harris et al. discuss museum-based training for future practitioners or scientists—graduate students, postdoctoral fellows, and advanced medical students—and present in detail sustainable models that can be easily replicated or adapted for different collections and considerations, especially in areas where training and professional development tend to be content-heavy. McMahon and Kovach zero in on effective collaborations for the undergraduate classroom and explain how a museum-based exercise in building observational skills not only helps introductory-level biology students hone observation and interpretation for scientific inquiry but also requires that they grapple with ambiguity and abstract concepts through association and metaphor.

Challenging Knowledge and Deepening Understanding through Engagement with Artwork

Just as science can inspire art, engaging with art in the museum can clarify and deepen understanding of scientific concepts, as well as, more generally, cultivate self-aware learners. The articles in this section acknowledge that teaching STEM concepts through art involves intellectual risk-taking on the part of instructors and students but can lead to the creation of new knowledge about course topics, as well as the artwork on which the class focuses. Through modes of creative, collaborative inquiry on the part of the faculty and the museum educator, and a willingness to momentarily depart from certain conventions of their different academic specializations, instructors can frame productive course engagements with art in which students apply what they have learned in class, gain fresh perspectives on STEM subjects, and begin to connect different ways of learning and knowing. Moasser's and Petersen and Kovach's contributions in this section show how teaching and learning with and through art enables instructors and students to reflect on how they learn, and to delight in the practice of learning.

Integrated Programs: STEM and Museum Practice

The articles in this section point to the centrality of firsthand, embodied viewing experiences with works of art and to how deeply and productively (or problematically) art and data can be intertwined. Kinney and Taylor's and Orr and Tapia Takaki's articles highlight art's capacity to raise new questions and provide insights into other academic disciplines and real-life situations, including the practices of the museum as an institution. Kinney and Taylor offer a detailed discussion of the course assignment in computer science they codesigned to transform their campus museum into a lab where students can fully experience the messiness of real-world data as presented by the authentic museum-database records for the artworks on view. Orr and Tapia Takaki position the academic museum as an active research partner, furnishing a rich example—an exhibition run as an experiment through the collaboration of a physicist, a curator for research, a mathematician, and a visual artist. Orr and Tapia Takaki push the discussion of data even further, suggesting that data as artistic medium can elicit—like more traditional art—affective, phenomenological, and other kinds of engagement with it. The integration of art and science in an educational and research context can yield generative, if not illuminating, conversations that open new ways of thinking and seeing.

Building a Sense of Belonging in the STEM Classroom and the Museum

The articles in this section demonstrate that teaching in the art museum can help students feel a greater sense of belonging in STEM courses. Based on a museum visit by her introductory geosciences course, for example, Cholnoky shows how a session on observation, interpretation, and critical thinking skills can spark the interests of students from outside the sciences and prompt richer interdisciplinary, intellectual discussion among all learners in the class. In a dynamic format which references the dialogic nature of their curricular collaboration (and any between faculty and museum professionals), Urry and Simon affirm these claims, analyzing how, as observed in four iterations of an introductory physics seminar, teaching in the art museum makes core concepts more accessible to more students, thereby boosting student confidence, which in turn yields a more productive learning environment and a stronger sense of community in the class. Smith and Alvord's article details a similar curricular collaboration, which they designed specifically to develop students' intuitive understanding of physical phenomena, build their confidence to dive into the topic's technical and mathematical facets, and empower those among them with diverse identities and interests to pursue physics. In sum, thoughtfully planned course engagements with art promote creative, intellectual inquiry and discussion, enabling students to feel more comfortable with each other and with the subject matter—and in the museum as a place for experimentation, research, and inspiration.

At the end, we would like to acknowledge that the idea for this volume grew out of a colloquium, *STEM in the Museum: Teaching Skills and Content through Art*, convened by the Yale University Art Gallery and Yale's Poorvu Center for Teaching and Learning in October 2022, with the goal of highlighting innovative art-based pedagogies that enhance student learning in STEM fields. Several of our contributors (Cholnoky, Filipowska, Milkova, Moasser, Petersen, Raad, Taylor, and Urry) participated in the colloquium as presenters or moderators. The realization of this issue is further due to an existing professional collaboration between us, the editors; our own experience teaching with campus collections across academic disciplines; the foundational contribution of *UMACJ* editor Andrew Simpson to the theory and practice of object-based teaching and learning; and the visionary work of all the authors who agreed to share their pedagogies.

We are deeply grateful to Andrew, the contributors, and the peer reviewers, who provided most insightful feedback on a very tight schedule and whom we would like to thank personally: Taylor Allen, Heather Flaherty, Julie McGurk, Rachel Seligman, Sydney Skelton Simon, Anne Tiballi, Steven S. Volk, and Veronica White. We thank our respective directors Stephanie Wiles of the Yale University Art Gallery and Daisy Desrosiers of The Gund at Kenyon College and all the colleagues who have fueled our ideas and helped us imagine new possibilities and connections.

Using Art to Foster Observational Skills in an Introductory Biology Lab

Jennifer McMahon and Jodi Kovach

Observational skills are important tools for many STEM fields and should be promoted alongside other technical skills in introductory laboratory courses. As a part of the curriculum for Introduction to Experimental Biology, students engage in a prolonged observation exercise at The Gund, Kenyon College's teaching museum, using Cy Twombly's portfolio of ten lithographic and mixed media prints, "Natural History, Part I, Mushrooms" (1974). The subject matter and imagery in these prints evince connections between art and science, making them an ideal choice for this class session. The exercise challenges students to develop and discuss their interpretations of these visually complex works and requires that they make observations for longer time periods than may be customary or comfortable. This exercise takes place early in the academic calendar and feeds into later lab activities that reinforce the imperative role of observation and interpretation in biological inquiry.

While often misunderstood as a simple cycle of asking questions and running experiments, scientific inquiry is a complex process that unifies cognition, intellect, and sensory input. Those doing research must first gather information in order to develop experimental questions, and this happens principally through observation. Observation is at the core of scientific inquiry, and its practice generates discoveries that drive research. Observation as a tool is important at all points of scientific investigation; it generates initial questions, helps the observer to find patterns, and it links prior experience or knowledge to the present (OGUZ-UNVER & YURUMEZOGLU 2009). Observation is not unique to the scientific domain, of course; it is broadly used any time an individual couples sensory input with awareness. While foundational to the scientific process, the ability to make observations is present early in human development: infants imitate others by observing them; children learn from observations as early as two years of age; and children as young as four years old are capable of making observations that lead to testing and problem-solving (FAGARD et al. 2016; KLEMM et al. 020).

As a component of scientific research, observation is certainly more than "just seeing"; it relies on information collected by all the senses and is sometimes aided by complex instrumentation that expands the limits of what can be detected. Observation quality is also governed by the knowledge base and experience of the observer; increased knowledge and training lead to more proficient observation (HAURY 2002). A recently developed model defines scientific 'observation competency' according to five elements: describing, asking, assuming, testing, and interpreting (KOHLHAUF et al. 2011). The model also stipulates that in order to achieve mastery, observations should proceed methodologically, and they must also connect to disciplinary knowledge (EBERBACH & CROWLEY 2009; KRAUS 2023). Eberbach and Crowley (2009) argued that when observation is not attached to field-specific knowledge, then authentic scientific observation cannot occur, and observation will remain mostly superficial. Since it is unlikely that students in a classroom already possess a sufficient breadth of knowledge in a given discipline, they must be guided through observational activities. Oguz and Yurumezoglu (2007) noted that students who employed a structured approach to observation developed research questions that were more detailed, diverse, and comprehensive than students who engaged in unstructured observation. Thus, in disciplines where experimental approaches are employed, observational practices should also be mindfully incorporated and should be contextualized with information that is appropriate to the educational level of the students.

Observation requires cognitive effort and, with practice, can be developed into a potent skill. With the recognition that observation is an important part of technical training, several educational programs have initiated the development of classroom exercises that promote observational practice, particularly in disciplines that are dependent upon qualitative analysis. Perhaps no discipline has invested in this approach as much as the health sciences, where observation is critical for accurate diagnoses in clinical settings. The interdisciplinary *medical humanities* field has evolved from the intersection of medicine with several non-science disciplines, including the fine arts, and has spurred innovative approaches to health and disease. Although there are several pedagogical approaches that have been developed for medical humanities curricula, the most commonly cited technique is the use of Visual Thinking Strategies (VTS) (BENTWICH & GILBEY 2017; PARKER et al. 2022; SLOTA et al. 2022). VTS is a framework for interpretive discussion after slow and intentional observation of art and has been correlated with greater visual literacy and critical thinking (WELLBURY & MCATEER 2015). Interestingly, VTS approaches with art also appear to correlate with enhanced 'tolerance for ambiguity' in medical students (BENTWICH & GILBEY 2017). Recognition and acceptance of ambiguity in visual arts can teach students to be more open-minded about medical situations that are not clear-cut, i.e. conditions which may be diagnosed in more than one way.

The rise of interdisciplinary medical education has naturally included a growing conversation between medical schools and institutions that collect and exhibit fine art and employ museum educators. Yale's School of Medicine was one of the first institutions to formalize observation practice (VTS) in their curriculum, collaborating with the Yale Center for British Art (YCBA) to train first-year medical students (DOLEV et al. 2001). This initial study reported that students who practiced focusing their observations on a single painting were able to more comprehensively describe patients with medical disorders than students who had received only traditional lectures. Since that early study, which gave way to the YCBA's *Enhancing Observational Skills* (EOS) program, visual literacy programs with observation exercises have been incorporated into the curricula of medical, nursing, ophthalmology, and even veterinary schools (WELLBURY & MCATEER 2015; FRIEDLAENDER & FRIEDLAENDER 2013; GURWIN et al. 2017; MANGIONE et al. 2018; HE et al. 2019; RANA et al. 2020; FERNANDEZ et al. 2021; PARKER et al. 2022; SLOTA et al. 2022).

Health sciences have invested heavily in art-mediated education to foster better clinical practice, and in recent years new pedagogical approaches to teaching STEM via the fine arts have gained currency at colleges and universities where faculty have opportunities to collaborate with museum educators specializing in undergraduate- and graduate-level curricular engagement with art. In 2009, the Mount Holyoke College Art Museum, supported by a grant from the Andrew W. Mellon Foundation, became the first art museum to adapt the EOS program at the undergraduate level, initially for the postbaccalaureate program for premedical students. This led to a larger, more experimental collaboration with the biological sciences at Mount Holyoke (ALVORD & FRIEDLAENDER 2012).

Many studies have shown that careful observation, description, and interpretation of visual art can promote the development of analytic and synthetic thinking skills and improve visual literacy, collaboration, and communication among students in science disciplines (GURWIN 2017; MILKOVA et al. 2013). Indeed, the seminal document *Vision and Change* (2011) charged STEM educators to incorporate more interdisciplinarity into their curricula in order to engender creativity, promote communication between disciplines, and support broader understanding of biological phenomena (American Association for the Advancement of Science 2011). In recent years, scholars in STEM fields have discovered how integrating art in targeted areas of a curriculum can strengthen students' understanding of concepts inherent to the field. For example, Ezin et al. (2020) demonstrated how guided observation of artwork can cultivate and develop skills essential to analysis and interpretation in biology—in these cases, skills that are difficult to teach in cell biology and that are crucial to recording accurate, detailed, and comprehensive data. The authors proposed two ways to bolster the practices of observation and quantifiable analysis among their students by teaching with art at their respective academic institutions. Among the exercises described, students at Loyola Marymount University practiced drawing accurate and precise illustrations of material observed in an embryology lab to sharpen their observation. At Touro University California, master's students in a molecular cell biology course compared abstract paintings to microscopic images, analyzing anomalies and patterns in each to understand what to look for when studying samples of tissues under a microscope and how to translate their findings into numerical data.

STEM research is a dynamic process and requires a broad range of higher-order skills, including critical thinking, observation, communication, reflection, and addressing information that may be ambiguous or without order. Milkova et al. (2013) reported that students who engaged in art-based exercises in upper-level biology courses demonstrated higher analytical ability, enhanced curiosity, and better reasoning skills. This same study also reported that students recognized intersections between course topics, other biological fields, and other disciplines. Programs based at art museums are uniquely poised to foster opportunities to practice these skills, and classrooms, particularly college classrooms, with curricula that intersect with fine arts in the museum have reported enhanced higher-order skills in their students. Engaging with art in the physical space of the museum facilitates discussion and collaborative approaches to exploration and problem-solving by providing new environments that are different from a traditional classroom, potentially leading to 'transformative learning' that is disruptive and unfamiliar (CHISHOLM et al. 2020). Individuals who are challenged with uncertainty are more likely to engage in the exchange of ideas, to ask questions, and to reflect on what they see.

The exercise we have developed and conducted each academic year since the spring of 2018 seeks to sharpen observation and train attention, but it also calls into question the very notion of 'accuracy' in the interpretation of visual information in order to engender an inquisitive sensibility in learners that is essential to research when encountering new and unfamiliar material in the laboratory. In other words, rather than requiring students to draw conclusions, we frame their encounter with artwork openly and strategically: to condition their intellectual faculties for engaging in careful processes of looking, reflecting, and developing questions.

STEM Faculty Development Workshop

The exercise in building observational skills discussed here developed from a workshop series that took place at The Gund in the fall of 2017, titled "Developing Metaphoric Thinking through Art and Science." Organized and moderated by the deputy director of curatorial affairs and education, the goal of this program was to support Kenyon science and mathematics faculty interested in exploring ways of teaching with 20th- and 21st-century art to enhance students' creativity, communication, and critical thinking. This workshop included ten faculty from biology, chemistry, physics, neuroscience, and computer science who wanted to augment skill sets necessary for their fields by engaging their students with resources from the fine arts. Participants learned from guest speakers and explored pedagogical approaches that faculty and museum educators at other institutions had employed to increase students' visual literacy. The workshop's focus on STEM-faculty participation highlighted the importance of students learning basic techniques that transcend disciplinary boundaries.

The premise for this program was the idea that by using art to mediate students' exploration of scientific concepts, we exercise the imagination and creativity to inspire new ideas and modes of inquiry that expand the formal structures used to communicate math and science principles. The type of thinking we wanted to cultivate was metaphoric thinking, which is often considered a tool of artistic creativity because it reflects the work of the imagination, yet it requires the mind to perform a complex integration of different concepts, essential to all intellectual processes (LAKOFF & JOHNSON 1981). A primary goal of the workshop series was to enhance metaphoric thinking in Kenyon STEM courses in order to improve students' critical thinking and their ability to produce new forms of knowledge.

The workshop featured a series of guest interlocutors—museum educators and STEM-faculty collaborators from peer academic institutions—who shared with the Kenyon participants methods and benefits of teaching course content through art. With our guest scholars, we explored a range of pedagogical methods that show how using art to teach STEM topics can:

- Help students understand how analogy, metonymy, narrative thinking, metaphor, visual perception, and imagination are instrumental in both artistic creativity and scientific thinking.
- Enable faculty and students to explore how metaphoric thinking shapes our perception and interpretation of the world.
- Stimulate student participation in discussions, group work, and collaborative assignments that explore the meanings behind certain formal structures in art, math, and science.
- Provide opportunities for exercising analytic skills, synthesis of different concepts, deeper engagement with course content, and cross-disciplinary application of knowledge gained.

While the Kenyon faculty participants had not necessarily collaborated with one another in a learning environment before, each session gave them the chance to work together in small groups on sample exercises conducted by the guest interlocutors. The guest roster included Elizabeth Cavicchi, an instructor at Edgerton Center, MIT, whose exploratory approach to teaching science inspired the observation exercise that we conduct annually for Kenyon's Introduction to Experimental Biology course. Drawing from John Dewey's theory that art is an amplification of life (DEWEY 1934), Cavicchi created a seminar that she teaches at the Edgerton Center, titled "Recreate Historical Experiments, Inform the Future with the Past," in which she invites her students to engage with art and the physical world through observation, but without providing them with any specific goals or anticipated outcomes. In other words, she teaches observation as an activity that can help us become open to new discoveries by unsettling the assumption that learners must answer questions and solve problems. In this exercise, learners encounter problems and raise questions; rather than drawing conclusions that affirm what we know, they begin to find ways to create knowledge. Art and nature are ideal subjects for this type of experiential learning because both invite aesthetic engagement, which opens up our minds to mystery and ambiguity.

In her presentation to Kenyon faculty, Cavicchi explained that establishing the conditions for students to practice observing both natural phenomena and works of art without giving them specific instructions or objectives suspends students in moments of productive uncertainty that often result in extended periods of silence, confoundment, and frustration. She encourages students to embrace this feeling of discomfort by allowing themselves the intellectual and creative freedom to formulate questions about what they cannot explain or do not understand. By having the Kenyon faculty take part in an activity in which they looked at artwork with the goal of simply observing, Cavicchi helped them realize that these feelings of perplexity, if sustained for long enough and shared with their peers, lead to a collective, generative curiosity. She showed that the experience emerging from the activity begins to give form to a community of learners who work together, honing the practice of observation as a means to raise questions collectively, which can open opportunities for further research (CAVICCHI 2017).

Engaging Biology Students in the Art Museum

The course in which we implemented this exercise, Introduction to Experimental Biology, is a yearlong class required for students who major in biology, molecular biology, or neuroscience. Students who plan to major in chemistry, environmental studies, or biochemistry also frequently take this course. The visit to the gallery takes place during the early part of the fall semester, when students are beginning to design their own experiments for an insect behavior lab. In preparation for the gallery session, students read "The Power of Patience," by Harvard University art historian Jennifer Roberts (2013), in which she explains how she develops students' ability to find meaning in images by taking the approach of 'deceleration' as a way to slow students' conditioned pace of looking so that they may realize the details and structures of what they are seeing.

The museum visit begins with a brief introduction by the museum educator, who explains the exercise to the students and contextualizes the artwork with which they will be engaging. After this five-minute introduction, students divide into groups of two or three and choose a single work to view. Each group spends ten to fifteen minutes observing their piece and making comments with their partner (fig. 1). Groups are then instructed to visit another print from the same series to discuss additional observations for another ten to fifteen minutes. After this second round of observations, the entire group reconvenes, and students are prompted to share their analyses with the rest of the class. Students are finally asked to reflect upon what they noticed as they remained with their work over the period of observation, which

Fig. 1, from left: Students in an introductory biology lab view and discuss Cy Twombly's *Natural History, Part I, Mushrooms* (1974), in The Gund's curatorial classroom, fall 2022 | Students engage with the series in the Buchwald-Wright Gallery at The Gund, fall 2019. The series has been displayed for these class sessions in several locations in The Gund's building. Photographs: Jennifer McMahon

is just long enough to test their patience and push them to look more carefully and deeply. By working in small groups to unpack the form and content of these works, students engage in a collaborative activity that begins to sharpen their observation skills and helps them appreciate that time devoted to careful looking is an important mechanism of learning.

Our choice of artwork for this exercise is strategic: while many works of art invite prolonged observation, we initially chose a series of prints from The Gund's permanent collection of modern and contemporary art by Robert Rauschenberg, *Rookery Mounds* (1979), for several fortuitous reasons: 1) with nine prints in the series, students in a class of approximately fifteen could easily work in pairs to observe a work of art that was different from what each of their peer groups were viewing; 2) students and their partners could easily switch to another work when prompted and would encounter a similar set of problems concerning form, structure, and content, thereby effectively building on their observations of the previous work; 3) these prints, and Rauschenberg's practice generally, invoke familiar imagery in compositions that challenge the conventional modes of interpreting an image.

The second time we conducted the activity, The Gund had received a gift of mixed-media lithographs by Cy Twombly, titled *Natural History, Part I, Mushrooms*, which offers advantages similar to those of Rauschenberg's prints.[1] The subject matter of this particular print series, mushrooms and mushroom hunting, also aligns perfectly with the objectives of our collaboration because of how the artist uses it to explore the connections between the disciplines of art and science. We have continued to work with these prints ever since the fall of 2018, and they have become an integral and highly recognizable component of the Biology 109 curriculum.

Twombly's *Natural History Part I, Mushrooms* resists definition and explanation. In creating these lithographic prints, the artist experimented with printmaking methods and added mixed-media elements, allowing meaning to emerge through the materials, processes, gestural drawings, and written words, which create a visual syntax that is conceptually and aesthetically consistent with the abstract drawings and paintings for which Twombly is best known. Yet these prints are the first artworks in which Twombly incorporated representational imagery—in particular, mycological illustrations from 18th-century natural history textbooks—to present mushrooms, and specifically their historical, cultural, and scientific significance, as subject matter.

Careful observation and deep study of *Natural History, Part I, Mushrooms* informed a theory that the prints invite a way of looking that is akin to the downwardly cast gaze one employs when mushroom hunting, a pastime that Twombly enjoyed (WALLS 2014). This type of looking requires visual acuity for identification and an oscillating movement of the eyes in scanning the forest floor to find a particular species of mushroom. The author notes that this way of looking while moving through the forest induces a contemplative state of mind, shifting the intentions of the hunter/viewer from searching for one object to exploring and discovering different objects within the field of vision.

Indeed, there always seems to be something new to identify and ponder in these prints: the compositions contain multiple layers of visual information—found photographs, scientific data and notations, aggressive marks alluding to the forms of mushrooms and their metaphorical associations, mycological illustrations, copies of pages from Leonardo da Vinci's sketchbooks, written words referencing classical mythology, and more—which require viewers to look at these patiently and carefully in order to begin describing to their partners what they notice to be interesting, curious, or confusing; to pose thoughtful questions to one another; and to articulate responses. Oftentimes, the conversations become lively, sparking new discoveries about the artwork. But the activity can also take the form of quiet, sustained looking and contemplation, which is just as important in conditioning students to slow down and to engage in processes of observation, interpretation, and reflection with intention.

When the students reconvene in the last third of the class time to share their observations, each small group comments on the prints that they focused on. This often prompts a conversation among all of the students, which the museum educator and biology instructor moderate by affirming student observations, raising questions, and offering subjective commentary. Because the goal of this discussion is to encourage students to continue making observations and questioning assumptions, no two class sessions are alike. In addition to having them describe their observations, we also invite students to share insight into how they experienced the exercise of looking at one work of art for a prolonged period, and it is not unusual for some to report having felt frustrated. We encourage students to comment on how they moved past feelings of boredom and perplexity in order to continue looking for the full ten to fifteen minutes. Art often suspends us in moments of ambiguity, which can be uncomfortable for learners who are accustomed to seeking rapid answers and providing accurate results. The frustration that can arise from observing a work of art reflects our discomfort with challenging our own assumptions and

[1] Works in The Gund's permanent collection can be found in the online collections database, https://www.thegund.org/the-gund-collection.

recognizing the limits of our understanding. Confronting the bewilderment of not knowing, however, can ultimately lead us to shift our perspective, to formulate questions, and to think critically and creatively about how to approach a problem.

Student responses to this exercise have generally been positive. Some individuals liked the exercise for the opportunity to engage with another discipline as a part of their training as a biologist. One student remarked:

> After visiting the art gallery I think that I looked at taking observations down about our experiments in a new way. I was more careful to take down all observations rather than only the ones that I thought were important because from the visit I learned that all details are important and can mean something bigger later.

Other students appreciated the change of pace that was warranted with viewing the art. One commented:

> Since my course load is STEM heavy, I have little time to stop, relax, breathe, and take in the world around me. I enjoyed this time to sit and observe such an abstract piece of artwork. This experience taught me that sometimes things take time to come to the surface; therefore, I need to slow down and truly take the time to analyze and observe.

Many other students acknowledged the ambiguity of the pieces they were asked to see and appreciated the opportunity to consider the ideas shared by others.

> I liked it. I thought that using small groups allowed us to voice our opinions without fear of embarrassment, and coming together at the end allowed us to get a diverse look at what the artist may or may not have set out to accomplish. I thought that it helped people understand the power in diversity of thought. We got some idea from looking at the single painting, but when we came together, we were able to bounce ideas off each other and see how they all came together. I personally am not a modern-art person, but I appreciated the time.

The experiences that the students described having with the artwork—becoming more attuned to the revelations that occur through careful observation, realizing how engaging with abstract art can inspire deep levels of thinking, and embracing the value of freely exploring ideas with their classmates and instructors—indicates that students are responding to conditions for learning that are unique to teaching STEM in the art museum. These conditions challenge students to inquisitively test their knowledge by making associations between seemingly disparate subjects and ideas. This is a form of cognition related to metaphoric thinking, which blends imagination and the generative integration of multiple ideas, and which is necessary for overcoming the instrumental approach to STEM teaching prevalent in American education (HENRIKSEN & MISHRA 2020).

Studies testing individual differences in metaphoric thinking show that while the use of metaphoric language, for example, does not correlate with intellectual abilities or personality traits, those who are more inclined to use metaphor are also more adept at grasping and explaining abstract concepts, at thinking associatively and creatively, and at linking thoughts and feelings to concrete experiences, which bolsters memory and critical thinking (FETTERMAN et al. 2016). The observation exercise that we conduct begins to cultivate this way of cognitively approaching and grappling with abstract concepts through association and metaphor; students are given the opportunity to explore the interrelationships between art and science, to develop a deeper understanding of biology by dwelling in the uncertainties of artistic and scientific knowledge, to articulate the meaning of intangible concepts expansively, and to recognize the beauty of the physical world that both art and science can reveal to us.

Conclusions

Spurred by challenges originating in *Vision and Change* (2011), STEM education has rapidly evolved to produce innovative and sustainable approaches to fortifying science education and to retaining potential new scientists. Because observational skills are foundational to STEM research, educators are developing pedagogical activities intended to strengthen this core competency. Collaboration with art museums has fostered observational practice, particularly in graduate health science programs, but undergraduate STEM programs are starting to catch up.

In the exercise introduced here, the Biology Department and The Gund at Kenyon College have developed a guided art-visualization exercise for an introductory biology laboratory course. The use of prolonged observation with modern art infused with ambiguity challenges students to engage more deeply with visuals with uncertain meaning and prompts active question development. Works of art chosen for the activity can vary, although using those in a series allows several students to focus on one or more works presenting similar questions concerning form, structure, and content. It is also important to choose art that challenges conventional modes of interpreting images. Discussion of not only the focal art but also the process of observation itself emphasizes the critical importance of mindful and measured interactions with sensory information. This exercise connects with other components of the biology curriculum that promote observational learning and research competency.

Acknowledgments

Thank you to the director and staff of The Gund at Kenyon College for the use of their space and the permanent collection for this class exercise.

The Gund (formerly the Gund Gallery) is the academic museum of Kenyon College, a small liberal arts college in rural Gambier, Ohio. Founded in 2011, The Gund has a growing collection of over four hundred works of late 20th- and 21st-century art. The museum also features loan exhibitions of contemporary art that typically change each semester and are featured in the Buchwald-Wright Gallery in The Gund's academic building. The deputy director of curatorial affairs and education is the museum educator at the museum who works with faculty of all disciplines to integrate the artwork in the collection and exhibitions into their teaching.

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Cultivating STEM Skill Sets with Art and Artifacts: A Teaching Workshop

Danielle Raad and Gina Marie Hurley

When students in science, math, and engineering turn their gaze toward art and artifacts, they develop essential skills and dispositions while deepening their understanding of disciplinary content. With the aim of increasing STEM interest in collections-based pedagogy across campus, we have developed and implemented a teaching workshop for graduate students and postdocs at Yale University. These interactive, in-gallery workshops expose new and future university-level instructors to object-based pedagogy and provide them with the space and scaffolding to think through why and how they would incorporate art and artifacts into their teaching. By focusing on skills and dispositions, rather than strictly content-based connections, we empower participants to develop a creative and reflective practice. This workshop, a successful cross-campus collaboration between educators based at a campus art museum and in a teaching center, offers a reproducible and sustainable model for providing experiential training for STEM educators in object-based pedagogy.

Starry Night is a dark nighttime landscape (fig. 1). At first glance, a viewer will see that the bottom half of the canvas is the earth and the top half is the sky, littered with stars. With some patience and sustained close looking, however, they will notice more details. The sky is painted in shades of blue with a hazy yellow glow, remnants of the sunset, on the horizon. Stars and their halos dot the background, many clustered together, some shining brightly, and a few shooting by with a trailing streak of light. Outlines of trees are sketchily resolved in the darkness and possibly rustle in the wind. The terrain is painted in subtle shades of brown and green. Faint marks of a road with clusters of bushes on either side stretch toward the gleams of the sunset, and perhaps two or three fireflies twinkle in the foreground. This oil-on-canvas painting, which hangs in the galleries of European art at the Yale University Art Gallery, was made by the French artist Jean-François Millet around 1850 and retouched fifteen years later.

Fig. 1: Jean-François Millet, *Starry Night*, ca. 1850–65. Oil on canvas. Yale University Art Gallery, Leonard C. Hanna, Jr., Class of 1913, Fund, 1961.22

Garrett Levine, a PhD student in astronomy at Yale University and a participant in a pedagogical workshop called "Cultivating STEM Skill Sets with Art and Artifacts," approached *Starry Night* because of its content connection to his field. He initially thought that he would design an activity identifying constellations or calculating the time of year based on the positions of the stars. As he engaged with the painting more deeply, Levine was struck by the fact that it evoked a familiar sense of wonder and curiosity about the night sky. The field of astronomy, with all its equations and calculations, can create a sense of detachment between practitioners and their intrinsic motivation for their study. *Starry Night*, however, reminded him why he became an astronomer in the first place. As he continued to reflect on the painting, he was struck anew by the shared experience that unites astronomers across centuries and continents: looking up at the sky and wanting to know more.

It was then that Levine seized upon an idea for using this painting in his classroom. Rather than simply having students try to identify constellations, he would deploy *Starry Night* to encourage students in an introductory astronomy course to locate themselves as participants within a larger tradition of celestial wonder. At the start of the semester, they would reflect on the painting and then go outside to view the night sky, describing their affective reactions to both experiences. This activity would reframe the semester to come, motivating students by contextualizing the equations and calculations they needed to learn. At the end of the semester, they would return and repeat this reflection as a bookend to the course, considering how their perspectives and orientation toward the painting and the sky had changed. By reflecting on this painting, students would cultivate dispositions that are critical to them as astronomers and as scientists but often overlooked in STEM classrooms: the mindfulness that would attune them to their own sense of wonder as well as the patience that would transform an initial spark of curiosity into a sustained exploration of the field. By looking past the content connection, Levine was able to imagine an object-based pedagogical approach that activates students' affective responses to the world around them in order to build motivation across and even beyond the semester. In making this connection, Levine's observation recalls the well-established link between positive affective engagement and increased student motivation and retention of material.

Levine was a participant in one of the two workshops on collections-based teaching we designed especially for graduate students and postdoctoral fellows in STEM fields at Yale University. In this article, we propose a model for exposing the next generation of STEM faculty to object-based teaching via a workshop that offers both training and motivation to incorporate art and artifacts in their teaching. This article will articulate the goals of the workshop and describe its design, intended as a road map for educators based at other museums and centers for learning.

Overview and Goals of the Workshops

The "Cultivating STEM Skill Sets with Art and Artifacts" workshops were the result of a strategic partnership between collections and educational development units on campus. Raad was a postdoctoral fellow at the Yale University Art Gallery specializing in university-level teaching and outreach and is currently Curator and Assistant Director of the Stanford University Archaeology Collections. She holds degrees in anthropology, chemistry, materials science, and education and has experience in STEM research and teaching. Hurley, who is Associate Director of Teaching Development and Initiatives at the Poorvu Center for Teaching and Learning, holds an interdisciplinary PhD in medieval studies, with her scholarship bringing historical and theological perspectives to bear on medieval literary and material culture. Our collaboration was enlivened both by the shared interdisciplinarity of our training and our interest in object-based pedagogy.

The workshops, which occurred once each in the fall and spring semesters of the 2022–23 academic year, were held at the Gallery and advertised through the Poorvu Center (table 1). They counted toward the requirements for the Certificate for College Teaching Preparation offered by the Center, which provides pedagogical training to graduate students and postdoctoral scholars. By offering credit toward the certificate, we hoped to indicate the centrality and importance of object-based teaching to future faculty in the program, featuring it alongside other core pedagogical concepts like equitable teaching and rubric design. Participants signed up because they were interested in using art and artifacts in the classroom but had not yet considered how.

Our list of workshop goals, as shared with participants in the session handout, is presented in table 2. As Levine's creative response to *Starry Night* shows, central to our approach was a focus on practicing and developing crucial skills and dispositions through engagement with art and artifacts, in addition to potential content-based connections. We have found that taking this approach in a workshop setting makes it possible to foster a richly interdisciplinary conversation between participants. It also allows them to develop a holistic and human-centered philosophy of teaching, one that cultivates transferable skills and dispositions, an approach that has become especially pressing in STEM education.[1] The workshop sessions proceeded in three parts: a close-looking exercise, a metacognitive reflection on scholarship paired with a skills-based approach to object-based teaching, and, finally, an activity centered on backward design with gallery objects.

[1] Milkova and Volk (2015) have described the way that intentional engagements with art objects can help students cultivate skills that transfer across disciplinary domains of knowledge and context. More broadly, holistic student development is a critical part of conversations around equity in STEM. For example, Dewsbury and Brame (2019) note that building students' sense of belonging, engagement, and self-efficacy is critical to their success and well-being in the STEM classroom, a space which also prioritizes a high volume of content. Additionally, when students develop a habit of information-seeking and reflection as part of their STEM education, they are more likely to remain within the major, developing an identity in STEM (PEREZ, CROMLEY, & KAPLAN 2014). One representative example of this approach is the course Being Human in STEM, described by Bunnell, Jaswal, and Lyster (2023), which prioritizes community and empathy in STEM classrooms. A version of this course is taught at Yale by Rona Ramos, Lecturer and Graduate Services Coordinator in the Department of Physics.

Part 1: Close Looking: Lowering the Barrier to Entry to Object-Based Teaching

Through a close-looking activity with a work of art, participants were able to experience what active learning looks and feels like in the gallery space. In the first iteration of this workshop, we gathered around Albert Bierstadt's *Yosemite Valley, Glacier Point Trail* (ca. 1873), and in the second we used Jean-François Millet's *Starry Night* (ca. 1850–65). In both cases, we chose pieces that had potential content connections—geology and environmental science for *Yosemite Valley* and astronomy and physics for *Starry Night*—but that were evocative beyond those direct applications. For facilitators at other institutions, the selection of an object can be an opportunity to highlight particularly important (or understudied) pieces in their collection. This flexibility stems from what German and Harris (2017) have described as the essential 'agility' of all museum objects. That is to say, any object can be examined from a range of disciplinary standpoints, well beyond the art historical.

To initiate the close-looking activity in an inclusive and low-stakes way, we began by asking everyone to jot down a one-word impression of the work of art. In this simple activity that jump-starts the looking process, everyone spent a minute silently observing the painting, moving around as they did. Their one-word impression could relate to the piece in any way: it could be something they saw, were reminded of, or felt. We invited participants to share their word out loud with the group without explanation. Once everyone offered their one-word impressions, we prompted them to deepen and synthesize their responses, noting similarities and differences while describing the visual cues that led them to their impression. During this discussion, we employed prompting questions to guide their responses.

This introductory activity offered participants an easy way into a conversation about an object in an unfamiliar setting. It built a shared vocabulary for interpretation, while also showing them that they have the tools to do visual analysis as both observers and facilitators. Since many of them were new to thinking about teaching with collections, that confidence is essential for reaching the ultimate goal of inspiring them to bring their students into the museum. Experts in the field of object-based teaching have emphasized the importance of student belonging and agency within the museum and archives (HAYDEN 2015; EL-AMIN & COHEN 2018; MARINO 2018), and we propose that this effort begins with the instructor finding their own sense of ease and ownership in these spaces.

Part 2: Fostering Metacognitive Thinking and Emphasizing Skills-Based Engagement

To prompt participants to consider their own experiences of close looking and their unique classroom contexts, we provided a list of skills and dispositions that can be cultivated through object-based teaching (table 3). This list is drawn from the substantial scholarship of museum education and art-based pedagogy and its potential to instill skill sets and habits of mind, particularly in STEM courses (MILKOVA et al. 2013; ROBERTS 2013; MILKOVA 2017; BERRY et al. 2020). It also draws on object-based teaching more broadly, such as the work of Barbara Rockenbach (2011), who posits that engagements with unmediated primary sources help undergraduate students develop self-efficacy and critical thinking. Our list of skills and dispositions also responds to the increasing investment in educating STEM students holistically, rather than a narrow focus on content delivery.

Working in small groups, students considered how they might use the painting in front of them to develop one or more skills from the list. Frequently, participants turned back to the close-looking activity, using what they learned as a model for how they might lead a session with students. In our second iteration of the workshop, we centered our opening activities around *Starry Night* so that we could provide the framing example of Garrett Levine's response to the piece.[2] Through this small-group discussion, participants justified for themselves and each other the merits of a skills-based approach to objects, as well as its potential applicability in STEM courses. They also began to think more independently about course design, which scaffolded their progress toward the final part of the workshop.

At this stage, participants were prepared to conceptualize what they had experienced so far. Therefore, we led a discussion on the scholarship of object-based teaching in order to root this workshop and their future pedagogical practice within scholarly methodologies. In our design of this workshop, we follow

[2] The selection of Millet's *Starry Night* and its connection to patience and mindfulness was inspired by Sydney Skelton Simon's use of the work in a gallery-based lesson for undergraduate students enrolled in Physics Meets the Arts, a course taught by Ágnes Mócsy (SIMON 2019).

Chatterjee and Hannan (2015) in contextualizing object-based teaching within the long history of work on experiential learning. Chatterjee and Hannan make this connection because of the way that working with art and artifacts requires students to use multiple senses. As they suggest, object-based teaching enhances student learning precisely because of its experiential, multisensory elements: it opens up new modes of engagement and knowledge formation. Within the session, we highlighted two of the many pieces of scholarship that informed our plan, both of which provided a theoretical framework for participants' own pedagogical practice: Kolb's experiential learning cycle and questions to structure close looking.

We modeled Kolb's experiential learning cycle throughout the workshop, priming participants for a more explicit introduction to the concept itself. Kolb suggests that learners must be actively engaged in an experience in order to advance their knowledge.[3] From this initial stage of experience, the learner must proceed through subsequent stages of metacognitive observation, conceptualization, and, finally, active experimentation (KOLB 2014). By linking the particularities of object-based approaches to more widely applicable pedagogical theories, it is our hope that participants will emerge not just with an understanding of how to integrate collections into their classroom but also with a theoretical framework through which to understand their teaching.

Next, we discussed the art of asking questions to guide the process of close looking with an object. In the handout, we provided participants with a table of questions and their purposes, making explicit how wording questions slightly differently can elicit different trains of thought and verbal responses (table 4). This table of questions, developed by Jessica Sack, the Jan and Frederick Mayer Curator of Public Education at the Yale University Art Gallery, is inspired by Visual Thinking Strategies (YENAWINE 2013; HOUSEN, YENAWINE, & BROOKSHIRE 2018) and Bloom's Taxonomy (BLOOM, KRATHWOHL, & MASIA 1984).[4] We also emphasized the importance of soliciting multiple responses to each question before moving on to the next. This table and discussion equipped participants with another tool to facilitate a conversation with a work of art, which they then took with them in the third activity. The appendix in the handout provided an expanded bibliography for follow-up reading.

Part 3: Putting Backward Design into Practice with Collections

In the final activity, participants experimented with what they had learned so far by designing their own object-based lesson plan (table 5). This was a scaffolded experience, through which participants proceeded from naming semester-long course goals to delineating the specifics of their lesson plan for a single class meeting. Since the activity was grounded in backward design methodology (WIGGINS & MCTIGHE 1998), it served as a fundamentally translatable structure and strategy for lesson design across the contexts in which participants might teach in the future. Participants gained both independence and inspiration, since they had the opportunity to share their ideas with one another, highlighting the benefits of finding a community of practice.

We began by asking participants to pick a class, either one they were currently teaching or one they hoped to teach, for which they would create an object-based activity. By choosing a specific course, they were able to align the goals of the exercise they designed with larger-order course objectives. As we have suggested, object-based teaching develops skills and dispositions that go well beyond direct connections to content. However, in order for that process of development to be successful, faculty members must be transparent in their articulation to students about what they hope to achieve. Transparency about course goals is an equitable practice, because it allows students to find motivation in the learning process and track their progress. As we discussed with participants, such transparency pays special dividends in content-driven STEM courses, because faculty are so often pressured to cover large amounts of material.

[3] Kolb's experiential learning cycle is rooted in the theories of Dewey (1899) and Piaget (1929), which both suggest that experience, rather than passive knowledge absorption, is the optimal way for students at all levels to learn and integrate new knowledge. For a fuller discussion of this connection, see Chatterjee and Hannan (2015). In this article, we have focused upon the ways in which metacognitive observation can shift students' dispositions and habits of mind. For an alternative approach, see Carol Roger's (2002) reflections on Dewey's *Democracy and Education*, which names reflection as a simultaneously personal and communal opportunity for students to connect with their moral grounding.

[4] This list of questions has been used by educators at the Yale University Art Gallery for many years to guide close looking in gallery sessions. Sack and Thompson (2024) published an article that describes the questions and their structure in more detail.

When they articulate their goals, faculty justify time spent in special collections to their departments in addition to their students, validating a focus on skills and dispositions.

We placed boundaries around the lesson-planning activity to keep the focus on the goals of our workshop, allowing participants the space to be creative within a predefined scope. We wanted them to be efficient with their time, concentrating on skills development and backward design without getting overwhelmed by the sheer amount of artwork and artifacts at their disposal in the museum, which number in the thousands. We therefore preselected objects (four in the first workshop and three in the second) paired with suggested skills. We also provided appendices with concise background information about each object and an annotated map of the galleries.

Once participants identified a class for which to design the lesson and navigated to their selected museum object, they worked through a list of questions (table 5). These questions were designed to make participants scaffold student engagement toward specific learning goals, consider their own position as a facilitator, and clearly articulate the connection between their chosen object and the skill or disposition they hoped to cultivate.[5]

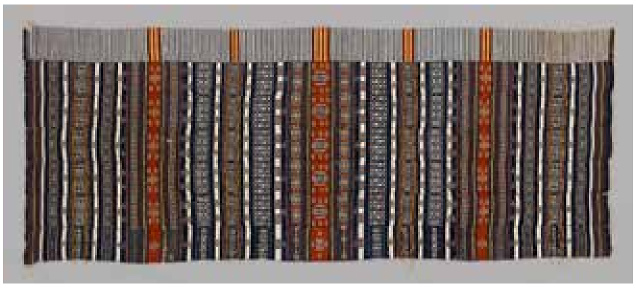

Fig. 2: Maabube weavers, *Marriage Bed-Screen (Arkilla Kerka)*, Fulbe [peoples], Niafunké, Niger River Delta, Mali, ca. 1985. Wool, cotton, and dye. Yale University Art Gallery, Gift of Shoreline Unitarian Universalist Society, 2019.41.1

At the end of both sessions, we reconvened as a group to share ideas. The lesson plans participants created showed their creativity and progress. For example, Rachel Renne, a PhD student at the Yale School of the Environment, examined a Maabube textile marriage bed-screen, mounted on the wall in the gallery of African art (fig. 2). She was struck by how much more detail was in the work than she originally expected from the thumbnail image in her handout. This made her consider how she might use the piece to teach remote sensing and mapping. In scaffolding this topic, Renne recognized that her students would need to understand the concepts of resolution and scale. This inspired her to plan a lesson in which they would stand at different distances from the textile, making observations about its pattern. Then, they would share their observations with others in the class, prompting a discussion of how features and details emerge at varying distances. Her reflections serve as a reminder of how we can help students process the materiality of objects as well the embodied experience of engaging with them. Both Renne's plan and Levine's ideas, shared in the introduction, demonstrate how participants found pedagogical inspiration through their engagement with these museum objects.

Conclusions

Overall, the feedback about this workshop from participants was very positive across both iterations. Participants reported they felt inspired to be creative in their approach, and they noted that the workshop sparked new ideas. In general, participants valued the opportunities to hear examples, whether those were examples we generated in advance or the activities that their peers designed. Particularly successful was the workshop's focus on modeling the experience of object-based teaching before leaping into design. Participants reported that this session gave them an understanding of why and how to use object-based teaching in their STEM classrooms, along with the confidence to do so. Finally, several participants found that the central idea of the workshop, that art and artifacts can be used to teach skills as well as content, resonated with them.

Throughout this workshop, we encouraged and modeled collaboration in a collections setting. In a report on teaching with primary sources, Tanaka et al. (2021) suggest that collaboration between collections experts and instructors leads to better learning outcomes for students. As co-facilitators, we modeled this collaboration through a dynamic workshop style, co-teaching each portion of the session and building on each other's expertise in discussion. As we suggested to participants, there are practical benefits to building those collaborations: it lowers the barrier to entry into unfamiliar collections, and it allows instructors

[5] To give participants with a source of inspiration if they became stymied in their planning, we developed an annotated list of common object-based active learning activities, provided in the appendix to the provided handout.

to focus on their specific course goals, rather than spending excessive time selecting pieces to discuss. However, there are intangible benefits as well. When instructors spend time talking about their teaching, or even co-teaching with another expert, they are exposed to new pedagogical approaches and have an opportunity to reexamine their own. What is more, as Volk and Milkova (2012) have suggested, "crossing the street" to work within the space of collections can disrupt academic silos across the university while helping instructors occupy the position of novice that their students experience regularly.

Participants gain exposure to the wider cross-disciplinary conversation about pedagogy through the integration of scholarship not just as a topic within the session but also as the bedrock of our design. The Yale University Art Gallery and the Poorvu Center for Teaching and Learning share a commitment to scholarship-informed pedagogy. Participants pursuing the Certificate for College Teaching Preparation, who take a range of teaching workshops offered by the Poorvu Center, emerge from the program with an understanding that teaching should be a fundamentally scholarly endeavor. By casting a wide net for educational research from the humanities, social sciences, and STEM, we hope to foster participants' appreciation for good teaching practices across the disciplines.

The central focus of these workshops, as we have suggested, is helping instructors design object-based lessons that cultivate skills and dispositions like evidentiary reasoning and patience in STEM undergraduate classrooms. These skills are simultaneously beneficial in all the spheres of students' lives—academic, professional, and personal—and closely aligned with disciplinary content. Our focus on skills-oriented goals also means that this workshop has several layers of transferability for participants. All of the Poorvu Center workshops for graduate students and postdocs emphasize transferability, since this is a population that is undergoing training to seek out positions at a wide range of institutions. As a result of their participation in this workshop, we hope that participants are therefore prepared to incorporate object-based lessons in any STEM course, selecting an object from any collection on any university campus. We hope that this workshop structure can serve as a roadmap for educators at other collections or centers for teaching to invest in the training of present and future STEM faculty alike. When instructors incorporate object-based teaching, they encourage students to perceive engagement with museums and other collections as a relevant and compelling new dimension of a more holistic STEM education.

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Keywords

object-based pedagogy, teaching workshop, STEM education, graduate and postdoctoral training

Are you looking for innovative ways to encourage STEM students to develop their critical thinking, acknowledge multiple perspectives, and enhance their communication skills? Research shows that engagement with the arts and special collections can do all that and more for students in STEM. In this interactive workshop, you'll learn more about the cognitive benefits of working with objects in the STEM classroom, and explore how special collections activities can build critically important skills. You'll walk away with an assignment or activity that you can implement in your own classroom—or show off for the job market!

Table 1: Description of the "Cultivating STEM Skill Sets with Art and Artifacts" workshop distributed in advertising from the Poorvu Center

1. Understand how to facilitate a conversation with students in front of an object.
2. Articulate the relationship between skills development and object-based learning in a STEM classroom, as well as the opportunities for content-oriented connections.
3. Evaluate how object-based teaching advances the goals of active learning, equitable teaching, and inquiry-based learning.
4. Design an assignment or activity for a current or future class that relates to the collections at Yale.

Table 2: Participant-centered and concrete goals of the workshop shared in the handout

- Patience and immersive attention
- Observation, visual literacy, and description
- Critical thinking
  - Generating and articulating analyses and interpretations
  - Evidentiary reasoning
  - Pattern recognition
- Acknowledging multiple perspectives
- Being comfortable with uncertainty and ambiguity
- Communication
  - Verbal presentation
  - Active listening
  - Collaboration
- Dispositions
  - Empathy
  - Mindfulness
  - Curiosity and a sense of discovery
  - Self-reflection

Table 3: List of skills and dispositions that can be cultivated by close looking and analysis of works of art, shared in the handout

Example	Purpose
What do you see?	Encourages students to describe or list what they see.
What do you notice?	Allows students to interpret the object, notice details, and observe relationships.
What is going on in this work?	Implies that there is more complexity to the work than may be apparent at first glance or that there may be a narrative to the piece.
What else do you see?	Encourages continuation of observation and discussion.
What do you see that makes you say that?	Makes students accountable for their observations by citing visual evidence.

Table 4: Questions to guide close looking, and the outcomes that they prompt, shared in the handout

(1) Pick a class to develop an object-based teaching activity for. This could be a current class that you're teaching or a future class you plan or hope to teach.

(2) Select an object and linked skill or disposition. Refer to the end of the packet for fact sheets about each of the three objects.

Object	Skill
• 1. Maabube Textile[6]	Pattern recognition
• 2. Albert Bierstadt, *Yosemite Valley, Glacier Point Trail*[7]	Generating and articulating analyses and interpretations
• 3. Jean-Michel Basquiat, *Diagram of the Ankle*[8]	Observation, visual literacy, and description

(3) Start to design an activity that helps students develop your chosen skill or disposition. On a separate piece of paper, write down notes to address some or all of the following:

- What activity would you do, and how would you structure it to scaffold students' development of the skill?
- What sort of framing would this activity require, and how would you make that transparent to your students? Consider:
  - The object itself (how you might introduce background information about the work or artist, and when)
  - The connection of this activity to course goals (for example, the development of critical disciplinary skills or mindsets)
- How would you guide the looking process (students' observations and focus)?
- What kind of discussion would you want to encourage?

Table 5: Instructions provided to workshop participants for the activity to design an object-based lesson plan

[6] See fig. 2 in this article.

[7] Albert Bierstadt, *Yosemite Valley, Glacier Point Trail*, ca. 1873. Oil on canvas. Yale University Art Gallery, Gift of Mrs. Vincenzo Ardenghi, 1931.389

[8] Jean-Michel Basquiat, *Diagram of the Ankle*, 1982. Xeroxed paper, oil stick, and acrylic on two hinged canvases. Yale University Art Gallery, Charles B. Benenson, B.A. 1933, Collection, 2006.52.11

Death and the Doctor: The Museum as a Tool for Understanding the Needs of the Dying

Jim Harris, Ashley Moyse, Gina Hadley, Rachel Lane, Sally Frampton, Ariel Dempsey, Joshua Hordern, Kate Saunders, and Gabriele C. De Luca

Over the past several years, the Teaching Curator of the Ashmolean Museum at the University of Oxford has been part of a multidisciplinary team examining the question of how we train medical students to deal with those parts of their profession which are concerned primarily with the humanity of their patients. This article discusses one such intervention, asking medical students in their fifth year (of a six-year program) to consider questions raised by their interactions with patients approaching and at the end of life, as well as their families and communities, including after the patients' death.

The preface to this article reflects broadly on a decade of medical collaboration at the Ashmolean; the article itself specifically on the processes of making and providing museum-based teaching on dealing with death, in a cross-disciplinary, nonmedical context, asking not only what the museum can do for medical education but why medical education might actually need the museum.

Preface, Dr Jim Harris

Medical Collaborations at the Ashmolean Museum 2012–23: Toward a Humanities-Based Curriculum for Teaching Medical Professionalism

For over a decade, in collaboration with colleagues from neuroscience, psychiatry, general practice, experimental psychology, history, English literature, and theology, the Ashmolean Museum has developed teaching in which the museum's collections and expertise in facilitating interdisciplinary dialogue have been brought to bear on questions of specific medical research, medical history, ethics, language and communication, the relationship of medicine to other fields of academic research, and the continuing professional development of practitioners.

Since 2017 or 2018, a principal focus of these collaborations has been to help define a place for the museum (and the humanities more broadly) in the teaching of medical professionalism to students nearing the end of their training—what it means to be a doctor and how to be a better one. Bringing together doctors, museum professionals, and Expert Patient Tutors (EPTs) in curriculum planning, this teaching has been delivered both online, using images from the Ashmolean's collections, and live, for example, by using the public galleries as spaces for the consideration of issues around death, dying, and end-of-life care.

The genesis of this work came shortly after the establishment of the Ashmolean University Engagement Programme, funded by the Andrew W. Mellon Foundation, in 2012. In the last months of that year and early 2013, a number of medical colleagues came to the Ashmolean Museum to discuss with teaching curator Dr Jim Harris ways of putting the collections to work for their students. They talked, drank coffee, and shared ideas, with the common aim of remaining open to whatever possibilities presented themselves. These meetings proved immensely fruitful.

In early interactions with students, the collections were offered up in a manner familiar from academic-engagement programs undertaken in other university museums, as source material for object-based learning sessions intended to improve skills of observation and the consideration of visual evidence, in order to improve diagnostic technique. However, it quickly became apparent that there was both an appetite and the potential to use the collections in other ways. For example, in light of a primarily observational class in early 2013, led by Dr Harris in collaboration with Dr Chrystalina Antoniades of Brasenose College and the Nuffield Department for Clinical Neurosciences (NDCN), one medical student, Jonathan Attwood, devised a museum-based experiment to measure the phenomenon of change-blindness in contrasting, simultaneous on-screen, and live-viewing scenarios. The experiment and its results were later published (ATTWOOD et al. 2018A; ATTWOOD et al. 2018B). Having qualified in 2017, Dr Attwood is now pursuing a career in clinical neuroscience. His legacy at the Ashmolean has been to open a series of encounters between medical sciences and the collections that engage both with the needs of professional training and the curiosity of those in professional practice.

A meeting, also in early 2013, with Professor Robin Choudhury, Fellow in Biomedical Sciences at Balliol College and Professor of Cardiovascular Medicine, led to an interdisciplinary seminar on the relationships between the heart as represented and understood in visual culture, from ancient Egypt to early modern Europe and Mughal India, and its actual physiology. This in turn gave birth to a public symposium featuring papers by art historians, conservators, surgeons, theologians, and literary scholars, held in the museum's principal sculpture gallery and attended by over two hundred members of the public. Another symposium followed in 2014, convened by Dr Harris and Dr Antoniades, addressing questions concerning the brain. Again, theology was represented, alongside experimental psychology, psychiatry, neurology, art history, and medieval literature; and again, the museum's principal sculpture gallery was full to capacity.

Notwithstanding the Ashmolean's appeal as a forum for interdisciplinary public engagement with research, and the success of a series of whole-day activities organized with Dr Antoniades and a team of neuroscience researchers and neurosurgeons as part of Brain Awareness Week between 2013 and 2019, public events have formed only a part of the museum's academic collaboration with the medical sciences at Oxford. Also of significance have been interactions on a smaller scale with a more specialized focus, falling broadly into three categories: classes given for preclinical and clinical medical students in general practice, psychiatry, and neurology; continuing professional development for practicing psychiatrists; and partnership in a humanities-based curriculum for teaching medical professionalism.

Class teaching in the museum as an adjunct to the medical curriculum has involved sessions offered to second-year students during their first experience working with general practitioners and to fifth-year students on psychiatric rotation, who are asked to consider both the historical image of the profession as seen through the eyes of the makers of early modern satirical prints (and their audiences), and as projected by doctors themselves in official portraits and book illustrations. These sessions deploy the Ashmolean's extraordinary Hope Collection of portrait prints and other works on paper.

Under the heading "Looking, Seeing and Understanding: Developing Medical Skills in a Non-Clinical Environment," fifth-year medical students in neurology undertake exercises intended to develop the linguistic skills required to communicate abstruse, complex information to nonspecialists such as patients and their families. In seeking to describe complex, unfamiliar objects to an audience of their peers, they work together to agree on a shared vocabulary and to acquire the critical listening skills to interpret what they hear. These classes have often been attended by EPTs, whose experience of chronic and degenerative neurological disease informs the discussion, immeasurably enhancing the students' learning and helping them to understand the dynamics of healthcare from the perspective of patients and their carers.

The collaboration with psychiatrists has taken the form of small seminars, attended by 8–12 doctors at consultant (attending) and specialist trainee (fellow and resident) levels. In these seminars, established in partnership with Dr Charlotte Allan, Dr Maria Grazia Turri, Dr Felipe da Silva, Dr Frederico Magalhes, and Dr Kate Stein, the medical professionals choose themes pertinent to the experiences of their practice, for example *The Body*, *Community*, *Rage*, *Suicide*, *Play*, and *Kindness*. As session convenor, the teaching curator chooses 10–12 works on paper from the museum's holdings of prints and drawings, and for two hours we pursue an open conversation. Through the session, the teaching curator acts variously as art-historical interlocutor, interested observer, and psychiatric naïf. The psychiatrists (and, as the sessions have continued, other medical professionals such as clinical psychologists) pursue questions springing from clinical experience, differences in approach, or issues in professional development—or simply take the opportunity to step away from practice for a short while (ALLAN et al. 2016; TURRI 2021).

Alongside these, it has been in the work of building a curriculum for teaching medical professionalism that one of the museum's most rewarding and challenging partnerships in medical education has come about. The Ashmolean's involvement in this project stems from two other, long-term collaborations, with Joshua Hordern, Professor of Christian Ethics in Oxford's Faculty of Theology and Religion, Dr Gina Hadley and Professor Gabriele de Luca of the NDCN, and Professor Kate Saunders of the Department of Psychiatry.

In the preparation of this curriculum, funded by the Wellcome Trust and the Nuffield Oxford Hospitals Fund, Professor Hordern's work on compassion in the ethics of healthcare and the training of doctors (in which Dr Harris has participated since 2013) has been brought into dialogue with the existing Ashmolean classes in neurology and psychiatry, and the expertise of medical humanities scholars including Dr Marie Allitt, Dr Ariel Dempsey, Dr Sally Frampton, and Professor Ashley Moyse. This team has combined to develop sessions using not only the resources of the museum but also historical locations in the university, photographic archives recording wartime medical care at Oxford, and the evidence of medical journalism. Like the "Looking, Seeing and Understanding" classes (and other, non-museum-related aspects of neurological and psychiatric education at Oxford), these sessions have been informed by the input of EPTs, including Rachel Lane, one of the coauthors of this article. During the preparatory phases of the medical professionalism project, a significant number of EPTs participated in a series of consultative events to garner their views on key aspects of the students' training.

This case study reflects on the experience of developing and introducing to the curriculum a three-hour, museum-based seminar addressing questions of death, dying, and end-of-life care.

Death and the Doctor: The Museum as a Tool for Understanding the Needs of the Dying

Summary

Doctors and other health professionals dealing with end-of-life care are routinely faced with diverse responses to death, dying, and its aftermath from patients and their families and communities. Responding appropriately to different and differently expressed needs requires physicians and their colleagues to speak with compassionate sensitivity and to think with intelligent agility. It also requires medical workers to express themselves in accessible, nonmedical language. This paper discusses a teaching session on death and dying aimed at encouraging medical students to consider some of the questions they may encounter in dealing with the dying and to weigh their own potential responses to the patients and families they encounter *in extremis*. The session, held at the Ashmolean Museum, Oxford, deploys objects and images to enable medical trainees to interrogate aspects of end-of-life care and to invite reflection on the challenges presented by the pursuit of this inevitable part of professional practice in a diverse cultural environment.

Introduction

A museum is a good place to think about death and dying. It is also a good place to encounter it. Museums are filled with the belongings and material residue of long-dead people, their images, the contents of their graves, the art they created, bought, and sold, and the memorials that were made to remember them.

Fig. 1: Unknown artist, *The Death of the Buddha (Mahaparinirvana)*, ca. 200 CE. Gray schist. Ashmolean Museum of Art and Archaeology, EAOS.10. Photograph: Jim Harris. © University of Oxford

However, despite the pervasive importance of death as a driver for cultural production (HALLAM & HOCKEY 2020) and as a theme in images and objects, and despite a professed willingness to speak of it, there is little evidence that substantial discussion of end-of-life is a part of most people's experience, certainly in the context of Western cultures (SALLNOW et al. 2022; Public Attitudes to Death and Dying in Wales 2022). Every doctor will encounter death in their training, but for the medical student this often happens first in the middle of a set of nights when there is no time to stop, still less reflect (RHODES-KROPF et al. 2005). As educators, we have a duty not only to prepare our students for these encounters but, in doing so, to secure the best possible experiences for both patients and their families.

The UK General Medical Council's Outcomes for Graduates states: "Newly qualified doctors must demonstrate that they can make appropriate clinical judgments when considering or providing compassionate interventions or support for patients who are nearing or at the end of life" (Outcomes for Graduates 2018). Yet the Royal College of Physicians 2018 report, *Advancing Medical Professionalism* (AMP), reminds its readers that such appropriate clinical judgment must attend also to the limits of medicine and the difficult conversations that must be pursued when confronting the actualities of dying and the "vulnerability inherent in such conversations" (TWEEDIE, HORDERN, & DACRE 2018). Compassion in such conversations requires a "two-way process of mutual understanding that involves openness to learning, change of mind and responsibility-taking by both doctors and patients," facilitating "companionship amid uncertainty, a sensitive approach to risk and intelligent reasoning and decision-making" (TWEEDIE, HORDERN, & DACRE 2018).

As part of the Medical Professionalism course embedded within the Brain and Behaviour (Clinical Neurosciences and Psychiatry) rotation in year five (of six) of the University of Oxford BM degree program, a session was devised with the intention of encouraging and enabling medical students to ask questions about their own experience of and encounters with death and about the possible and likely encounters they might have with colleagues, patients, their families, and other members of the communities in which they live. The session is run jointly by medical and humanities faculties in collaboration with the Ashmolean Museum and includes perspectives from patients who participate in the medical education curriculum.

We asked students to follow a path around the Ashmolean Museum, in groups of 6–8, examining a number of objects and images at seven stopping points in the public galleries. During their journey, in which each group self-guided, we invited the students to consider, alone and in conversation with their peers, several aspects of death and dying, using the objects and images to stimulate reflection. At each point we offered prompts for discussion, for example:

- Is it possible or necessary for the doctor to share the grief of the bereaved?
- How are privacy and comfort related in the approach to death?
- What impact might the perpetual awareness of death and its inevitability have on the health of the medical professional?

As can be seen in Appendix A, some of these questions overlapped, enabling students to revisit some topics, for example the relationship between the medical practitioner and faith, whether embodied in community leaders supporting patients and their families, as a factor in patient and family responses to questions of care, or with respect to the role of practitioners' own faith or beliefs in the context of dying and death. Other questions were pertinent to one particular circumstance or set of circumstances, for example with regard to the self-care of the physician or the encounter with the deceased body. It was hoped that exploring the collections of the Ashmolean with these questions in mind would make possible compassionate, listening encounters between the students, which would in turn attune them to the context- and person-specific encounters they would be likely to have in clinical practice.

Learning from the Exercise

This reflective journey was emphatically not intended as an art-historical exercise. Instead, as the students moved around the Ashmolean, they were encouraged to draw from the experience of long histories and diverse cultures, using the collections as tools for reflection on the end of life, and to interrogate the role of the doctor in the processes of dying and the aftermath of death (NICOL & POCOCK 2020).

Similarly, there was no intention to drive the students toward a correct or prescribed answer to any of the questions at issue, nor to constrain their looking only to the objects and images detailed in the guide. Rather, it was hoped that students might use the questions and prompts as stepping stones to a wider consideration of death beyond bodily decompensation and efficient causes (BISHOP 2011) and of the cultural output that our collective encounter with death has engendered (HALLAM & HOCKEY 2020), and to reflection on death as a universally shared but invariably uniquely experienced social phenomenon (SALLNOW et al. 2022).

After completing the Ashmolean trail, the cohort was gathered for a plenary session. Each small group was invited to expand on the ideas pertinent to one of the staging posts on the trail, discussing their experience of the images and objects they had seen and sharing any further questions raised during their discussion in the galleries. These reflections were then opened to the whole cohort, ensuring that as many voices as possible were able to participate. A recurrent theme that emerged was that students valued the space to consider not only the facts of the end of life but also the effects of death and dying on their patients, their loved ones, and themselves.

Feedback from participating students has demonstrated the need for space in the medical curriculum for precisely this kind of reflective, discursive work around death and dying, including making room for disagreement (see Appendix B). This space might also be expanded to include learning from patients themselves, which could help to narrow the "gap between what doctors are trained to do and the realities of modern practice" (TWEEDIE, HORDERN, & DACRE 2018). This returns us to the precise place of this session in teaching a curriculum on medical professionalism.

AMP explores seven key aspects of modern medical practice and professional identity: healer, patient partner, team worker, manager and leader, learner and teacher, advocate, and innovator. It also emphasizes three key values in medical vocation: integrity, respect, and compassion. The Ashmolean session maps clearly onto questions of patient partnership and advocacy, and also of healing, while particularly emphasizing the need for compassion in practice. The exercise itself is one of individual and group learning and peer-to-peer teaching.

AMP also acknowledges that the nature of the patient partnership might change, with a greater emphasis on end-of-life care when the body is shutting down but the patient is still cognizant. To explore this relationship more effectively, EPTs have been involved in shaping the Medical Professionalism curriculum and delivering teaching in response to the report. EPTs are trained to educate students about key elements of history and neurological examination signs specific to their disease, while providing constructive feedback about students' approaches, facilitated by clinician teachers.

As part of the development of the curriculum, EPTs with chronic neurological disease (multiple sclerosis, Parkinson's, and peripheral neuropathy) were asked to reflect on the seven key aspects of professional identity identified in AMP in a series of online meetings convened by Dr Harris and using images from the Ashmolean as focal points for discussion. In the case of healing, for example, the EPTs were asked if there was conflict between healing and cure, responding that if there is "no faith in a cure" then one had to "focus on healing." This reflects a key emphasis of AMP, which distinguishes cure from healing, with healing as the more encompassing vocation of doctors: "Healing starts with the relationship between the doctor and the patient, and compassionate, listening doctors can heal simply through their presence." (TWEEDIE, HORDERN, & DACRE 2018). Honesty around whether cure or healing was on the horizon was important to EPTs, as were trust between patient and practitioner and the consideration of the patient's faith position.

To address these issues in a museum context enables the subjective nature of a response to an image to underline the necessarily subjective response of the physician to the individual challenges posed by each patient they encounter. In the absence of the possibility for a single approach to end-of-life care, it is not the physician's courage that will enable difficult conversations to be pursued successfully but their ability to understand the specific needs of the individuals and communities in any given case. The capacity of the museum to present a range of cultural possibilities in a single afternoon makes it a unique resource to explore the demands made by the serial, daily reorientations expected of medical professionals.

Conclusion

It is important to distinguish this work from the many studies made of the utility of art objects in improving the observational skills of medical professionals (MUKUNDA et al. 2019; IKE & HOWELL 2022). We make no claim to fundamental novelty, merely of difference in intention. In this instance, the artwork serves not as a neutral tool, whose precise content is unimportant, but as a value-laden artefact whose content and context are useful in understanding both patient and self as equally complex and value-laden individuals working in relationship. This does not mean that the session is intended to 'humanize' the doctor-in-training, or to inculcate compassion through the encounter with the art object. However, we believe it has the effect of foregrounding compassion as part of a contextually appropriate response to death.

It is our hypothesis that this work will help train and empower doctors who are more capable of engaging compassionately in the unique circumstances surrounding the end of their patients' lives. Interest has been shown among general practitioners both in their own training and in their part in the education of medical students. However, we propose that this concept could and should be adapted more widely. There is not only interdisciplinary but also intradisciplinary relevance, with a planned extension of the project to allied health professionals including, but not limited to, nurses, clinical psychologists, physiotherapists, and occupational therapists. Towns and cities with institutions for training future healthcare professionals have museums, galleries, and other cultural spaces that can provide novel settings, separate from the confines of a clinical environment. This is not a practice constrained by the contents of any one museum but one capable of reinvention in light of whatever collections are accessible. What is offered here, therefore, is not a particular set of images and objects around this work must be built, but an adaptable idea for using images and objects. Death is one of the only certainties in medicine, and as such must be approached without squeamishness or coyness but equally in a manner which is not only medically but also personally and culturally appropriate. Museums are precisely the kind of capacious, heart-expanding space into which to invite medical students and professionals on a path to understanding what that might entail.

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Appendix A: The Structure of the Ashmolean Death and Dying Trail

The trail involves a journey to seven locations in the museum over the course of approximately ninety minutes, and a conversation between the students at each staging post, informed by encounters with particular objects and images and aided by questions posed in the guide supplied to each participant.

These are the seven staging posts, the prompts given, and the questions the students are asked to consider. Where possible, links are given to the objects and images in the Ashmolean's Online Collections.

1. **Encountering Death**

The dead Christ is one of the most important iconographies of death in the Western European tradition. However, this dead body is not always seen in the same way. The bloodied, wounded body is both familiar and unfamiliar. We see broken and traumatized bodies often in popular culture, but seldom in reality.

Anthony van Dyck, *The Deposition*, oil on canvas, ca. 1619
https://www.ashmolean.org/collections-online#/item/ash-object-372686

- How does the prevalence of death in popular culture affect how we think about it?
- Are we inured to the reality of physical trauma by the frequency of its depiction for entertainment?

In reality, a more familiar death is seen in the body cleaned and prepared for burial, or perhaps in the hospitalized body not traumatized by injury but wasted by disease.

These bodies will need to be dealt with in different ways depending on the needs of the bereaved. Although death itself is not culturally determined, responses to it, beliefs around it, and the treatment of the physical remains it leaves behind invariably are.

Pietro Testa, *The Dead Christ Mourned by Angels*, oil on canvas, mid-1640s
https://www.ashmolean.org/collections-online#/item/ash-object-373598

- What, if any, might the role of the doctor be in those culturally determined parts of the processes of death and dying?
- What help might a doctor need to seek when no healing is possible?
- Whose voices will need to be heard?
- What strategies do people employ to avoid the realities of death?
- What might be the role of the doctor in both mitigating and helping to recognize the approach and event of death?

It is commonplace for memorials of the 18th, 19th and 20th centuries to describe death as sleep, and this idealized body of Christ is laid out as if sleeping.

Unknown artist, after Jacopo Sansovino, *The Dead Christ*, polychromed terracotta, ca. 1610
https://www.ashmolean.org/collections-online#/item/ash-object-746284

- What strategies do people employ to avoid the realities of death?
- What might be the role of the doctor in both mitigating and helping to recognize the approach and event of death?

2. Death and the Everyday

Still-life painting is often full of reminders of death in the everyday objects of life.

Philips Angel, *Still Life of Game with Four Plovers*, oil on panel, ca. 1650
https://www.ashmolean.org/collections-online#/item/ash-object-372299

- What impact might the perpetual awareness of death and its inevitability have on the health of the medical professional?
- How do doctors care for themselves and each other in dealing with death?
- How can a doctor deal with precariousness in their interactions with patients and their families, and in their own life?

Clara Peeters, *Still Life of Fruit and Flowers*, oil on copper, 1612–13
https://www.ashmolean.org/collections-online#/item/ash-object-373327

- What other concerns, for example financial, might preoccupy the families of the dying during and after terminal illness and death?
- Is it ever the role of the doctor to address and help with those concerns?

3. The Death of a Child

The text on this gravestone ends with a prayer for the consolation of the deceased's parents, which often forms part of the inscriptions on the tombs of young children in the Islamic world. The aftermath of death may involve wider conversations in partnership, for example, with faith leaders.

Unknown carver, *Gravestone of a Muslim Girl*, marble, 431 AH/1040 CE
https://www.ashmolean.org/collections-online#/item/ash-object-388333

- What kinds of continuing care are required after death?
- How does a doctor manage the difficult conversations about death in talking to parents?
- How does the doctor remain involved in the processes of grief, or is there a moment for that responsibility to be handed over?
- What is the doctor's role in the space between the facts of death and the faith of those experiencing it?
- Is it ethical for a doctor to speak of faith and belief in the course of their interactions with patients?

4. Seeing and Not Seeing

The language used around terminal disease and end-of-life narratives often employs metaphors of battle—war and warriors, bravery and courage—with the disease playing the part of an implacable enemy or a wily monster to be fought and defeated.

This language can represent a very visible and open approach to death, placing the dying person in a publicly combative relationship with their disease or even with reality.

Unknown painter, *Amir Hamza Defeats Umar-i Madi Karab*, ink and watercolor on cotton and paper, ca. 1561–65
https://www.ashmolean.org/collections-online#/item/ash-object-356000

- Does it make a difference to the doctor to be cast in the role of a warrior in a battle?
- Is this language problematic or a useful set of metaphors to encourage and support the dying and the bereaved?

These Jali screens were intended to shield interiors from the sun and to create cool, private spaces (see fig. 2).

- How are privacy and comfort related in the approach to death?
- When is separation from the dying person a necessary mechanism medically, but a source of difficulty for the dying person and their family or friends?
- Has the shared experience of the pandemic modified your view of this?

Fig 2: Unknown carvers, *Jali Screens*, 19th century. Sandstone. Ashmolean Museum of Art and Archaeology, EAX.7346–.7348. Photograph: Jim Harris. © University of Oxford

5. Suffering before and after Death

In Buddhist tradition, bodhisattvas are enlightened beings who devote their lives to freeing others from suffering. Bodhisattvas are not worshipped but inspire others to reach enlightenment.

Unknown artists, *Figure of the Bodhisattva*, Jizō, polychromed wood, 16th century
https://www.ashmolean.org/collections-online#/item/ash-object-364677

- What are some of the expectations of the doctor around death and the preparation for death?
- Are you part of the process of release from suffering or part of the suffering itself?
- Is it possible for the doctor to fulfill the role of healer at the moment when no healing is possible, or is that the job of others?

The last words of the Buddha to his disciples before attaining final nirvana were, “All composite things must pass away. Be therefore mindful and vigilant!”

In this image, though, the Buddha’s followers are nonetheless depicted physically expressing their grief.

Unknown artist, *The Death of the Buddha (Mahaparinirvana)*, gray schist, ca. 200 CE (see fig. 1)
https://www.ashmolean.org/collections-online#/item/ash-object-354746

- Is it possible or necessary for the doctor to share the grief of the bereaved?
- Or the opposite?
- How does the doctor’s role change in light of the responses of the bereaved, whether stoic or emotional?

6. The Needs of the Dead

The question of what the dead need has preoccupied humans since prehistoric times, and the Ashmolean is full of the contents of graves. Grave goods also, inevitably, reflect the needs of the living for reassurance concerning the well-being of loved ones, the maintenance of memory, and the specific requirements of a particular culture.

Unknown sculptor, *Figure of a Horse*, earthenware, 701–50 CE
https://www.ashmolean.org/collections-online#/item/ash-object-358445

- How is the doctor involved with the needs of the dead?
- How do we manage these needs in conversations about end-of-life care?
- What conversations are necessary in preparing for death?
- How does the doctor play a role in maintaining the mental health of the families and friends of a dying person?
- How do we ensure our approach is culturally sensitive and appropriate?

Unknown maker, *Modified Human Skull*, plaster, shells, human bone, ca. 7000 BCE
https://www.ashmolean.org/jericho-skull

- Do we, those we treat, and their families fear the anonymity of death?
- Does the doctor have a part to play in maintaining the memory of the deceased?

This is one of the oldest pieces of sculpture ever discovered: a skull modified with clay, cowrie shells, and pigment. We have no idea what precise function it served or why it was made, but it appears to be an effort to give life back to the dead person.

Although death itself is familiar, its aftermath is unknowable and the continuation of existence is taken from the deceased and placed into the hands of the surviving friends and families.

7. Celebrating Life

Ideas about the afterlife vary from culture to culture, but many people share a powerful belief in life after death irrespective of religious faith.

Jacopo Robusti, known as Tintoretto, *The Resurrection*, oil on canvas, 1550–70
https://www.ashmolean.org/collections-online#/item/ash-object-373608

- How might a doctor's own belief system enable them to empathize with patients and their families facing death?
- Is it ethical for a doctor to speak of faith and belief in the course of their interactions with patients?

The potential for involvement in birth as well as death offers the general practitioner unique access to some of the most emotionally significant moments in the lives of individuals, families, and communities.

Unknown Flemish painter, *The Adoration of the Shepherds*, oil on panel, ca. 1560–70
https://www.ashmolean.org/collections-online#/item/ash-object-372824

- How might the celebration of life impact on the sensitivity of a doctor's approach to death?

Appendix B: Some Feedback from Medical Students on the Ashmolean "Death and Dying" Session

- "I really enjoyed space for open discussion; [we] rarely get the chance in med school. Created a space where people felt comfortable."
- "Coming here is really good—getting away from hospital. The conversations we had reflecting on prompts were really interesting—perhaps trail felt a bit rushed?"
- "Why have we not had a space to ask these questions earlier in our training?"
- "Prompted discussions we would not otherwise have. More time! The role of the doctor in the aftermath of death was something I had not really considered previously."
- "[It was a] really useful way of approaching the topic and much better than a lecture. Really made me think about the extent to which we shield ourselves from the reality of death and how alone that leaves the dying."
- "We say we are comfortable with death in our profession but Western Society is afraid of it."

- "The framing of disease a battle/war makes me think about the outcomes of a situation—there must be a winner or loser. However, medicine isn't so binary and often it's making the best of a bad situation. Death doesn't have to be a loss; it can be the last tied up chapter in a lovely book or a means to escape suffering. It is absolute, but doesn't have to be a loss, it's natural. I think [the session] will affect the way I use language in medicine moving away from the idea of a battle."
- "A lot of our answers to the questions came back to having an individual approach to each patient/family and being guided by what they want/need from the doctor and the rest of the team."
- "The role of a doctor in the death of a patient can be a very difficult topic, especially as the doctor feels separate to the patient and their family perhaps emotionally, but intimately involved in one of their most important and vulnerable moments. Thinking about how a doctor can utilise their role to help patients and families make the most of this time, by providing support is something I hope to take into my future practice."
- "[The session] made me think about what it means to grieve—to lose something, and how this can apply to miscarriage etc. as well as a 'normal' death."
- "I liked that we were left to discuss by ourselves rather than having a staff member facilitating as it allowed for more organic discussion. This session made me think a lot about what we consider to be a 'life well lived' and how this is often related to age."

Not all participants have found this to be a wholly positive exercise.

- "Today I reflected on the fact that whilst it may be therapeutic to reflect with peers [on] difficult experiences, this is not always beneficial. We should not feel expected to share intimate memories of death with peers who are unable to empathise with us. I think it is important to reflect in settings that feel safe, but not to feel that this is a requirement in all situations."

Some students reflected on the limitations of the role of the medical professional and the importance of other members of the wider team responsible for patient care.

- "Faith, like other aspects of identity, can be a quintessential part of what it means to be human. It is important for anything involving death and dying to be steeply patient driven. Personal faith can play a role in the end-of-life care of a patient, but we should be careful to let patients guide us in exactly how that looks. Asking someone if they'd like to be (linked) into religious services feels like a good way to do this and from then on Chaplains who are very specialised and good at what they do can take the lead, though we may at some point find ourselves in shared faith scenarios where that personal aspect of our identity can be quite powerful."
- "As someone who has worked in chaplaincy and has seen how beneficial chaplains are: uniquely trained to be faith questioners in healthcare. I don't see a role for the doctor and their personal faith in this process as we each have different roles which we are experts in."

Teaching Chemistry with Art

Bahram Moasser

Integrating artistic activities directly into introductory and advanced chemistry courses at the University of Notre Dame has proven to be an effective pedagogy for science learning. Examples of this approach include examining the symmetry properties of objects of art in the museum, discovering chemical reactions and principles through art, and exploring scientific ideas behind materials and processes used in artistic creations. The power of art in influencing thoughts in science can be analogical to help students connect ideas from one way of knowing to another. Alternatively, works of art can be a representation of ideas in science that can clarify complex concepts.

Introduction

The modern world requires a public skilled in scientific and humanistic knowledge and values. Thus, learning institutions are increasingly supporting an integrated approach to education. Accordingly, science educators are incorporating arts into science teaching (COSTANTINO 2018; MARSHALL 2015; SKORTON & BEAR 2018; TURKKA 2017). This approach has been called STEAM, an educational model that integrates arts into STEM. Scientists often use images to refine and reflect on their theories. Physicist Sir Roger Penrose famously uses sketches to visualize mathematical ideas. However, the visual arts can go beyond clarifying or communicating scientific principles. At its most potent, the arts can complement science in illuminating new ideas. An artwork can frame concepts or provide insight into scientific problems. By using or creating knowledge, science and art push our thinking to the limit of the possible.

In hopes of bridging the gap between science and art and demonstrating the value that each brings to the other, I've incorporated engagement with art in my chemistry courses. In this effort, I've collaborated with the Snite Museum of Art on the University of Notre Dame campus. This account summarizes how I've incorporated the museum into my teaching and analyzes its effect on my courses. This collaboration has expanded with the opening of the new Raclin-Murphy Museum of Art at Notre Dame. The Raclin-Murphy Museum includes a Teaching Gallery designed to display works of art for specific courses and an Object Study Room equipped with technology that can be used as a classroom.

Overview of the Courses that Incorporate the Museum in Teaching

During the past seven and a half years at the University of Notre Dame, I have taught three lab courses in the chemistry major sequence in which I have incorporated visits to the Snite Museum of Art (table 1). Although these courses have specific roles within the undergraduate curriculum, I have had the flexibility to design and implement creative exercises that link to the required concepts covered in the syllabus. For particular topics in the syllabus, such as symmetry, synthesis, and study of pigments, the visits to the Snite Museum of Art were essential to the pedagogy.

The four-semester introductory chemistry lecture/lab sequence at Notre Dame follows a 1-2-1 pattern of general chemistry-organic-general chemistry courses. *Introduction to Chemical Principles Lab* (Chem 11181) course is taken in the first semester. The course topics include reaction stoichiometry, molecular symmetry, molecular orbital theory, equilibrium, thermochemistry, and spectroscopy. The lab emphasizes critical thinking, such as forming scientific arguments based on the interpretation of data. In addition, students develop strategies for inquiry (asking interesting questions) and begin acquiring the tools for designing experiments. *Chemistry Across the Periodic Table Lab* (Chem 21284) is an advanced inorganic/physical chemistry lab. In between, students are exposed to a full year of organic chemistry, so when they arrive in Chem 21284, they are seasoned second-semester sophomores. The topics covered are transition metal bonding and spectroscopy, green catalysis, chemical kinetics, and reaction mechanisms. *Advanced Inorganic Chemistry Laboratory* (Chem 41443) is a two-credit laboratory course taken by seniors involving advanced inorganic and organometallic chemistry, including synthesis, symmetry, spectroscopy, kinetics, and reaction mechanisms.

There is anecdotal evidence over the seven and a half years that using art in chemistry teaching promotes deeper learning where students reflect on their learning and practice the method of learning by doing.

The tangible outcomes of this pedagogy, as evaluated from student feedback, are improved understating of the facts and principles of science.

Course Name	Target audience	Semester course is taken	Enrollment
Chem 11181	Chem/Biochem majors	Fall semester of 1st year	60-100 (2)
Chem 21284	Chem/Biochem majors	Spring semester of 2nd year	50-60 (2)
Chem 41443	Chem majors	Fall semester of 4th year	12-16 (1)

Table 1: List of University of Notre Dame chemistry courses discussed in this paper. In each case, the total enrollment shown is more or less evenly split into the number of sections (in parenthesis).

This continuing project has been a collaborative effort with Bridget Hoyt, the Curator of Education Academic Programs at the Snite Museum of Art. Typically, Bridget Hoyt and I meet to discuss the structure of the museum visits. We select artwork from the museum's permanent exhibits or the extensive collection for students to engage with. Works are chosen primarily based on their relevance to teaching chemistry. However, the selections often have historical, social, or cultural significance, or are characteristic of a particular style or artistic period. A lab handout is created, including artwork images and a list of questions for each. Recently, an instructional lab video has been made to accompany the lab handout. Over the years, we have looked at Decorative Arts, European and American Painting and Sculpture, Modern and Contemporary Art, Photography, Prints, and Drawings collection areas.

Methodology: Using Art in Teaching Principles of Symmetry

Symmetry: Change Without Change

A topic that lends itself very well to teaching in the museum is the systematic study of symmetry. Symmetry has a wide-ranging impact on understanding the structure and properties of matter. It summarizes the interrelationships of parts in molecules and regularities in crystals. Students find their first experience with symmetry challenging because defining and classifying symmetries relies on an intuitive understanding of spatial relations. Here is where art and chemistry intersect in a way that is both meaningful and fun.

Scientifically, symmetry is defined in terms of invariance with respect to change. Transformations of an object that leave it unchanged are symmetry properties of the object. A *symmetry operation* is an action that transforms the object into an indistinguishable version of itself. A symmetry operation is carried out with respect to a corresponding *symmetry element*, a geometric object such as an axis, plane, or point. Operations in *point symmetry* apply to the rigid motion of an object, meaning a transformation that does not move the center of mass of the object and does not distort it. The collection of symmetry operations of an object is called a *point group*. A point group can be used to classify any object.

Fig. 1: The Eiffel Tower. Source: https://pixabay.com/illustrations/eiffel-tower-3d-render-france-4582649/

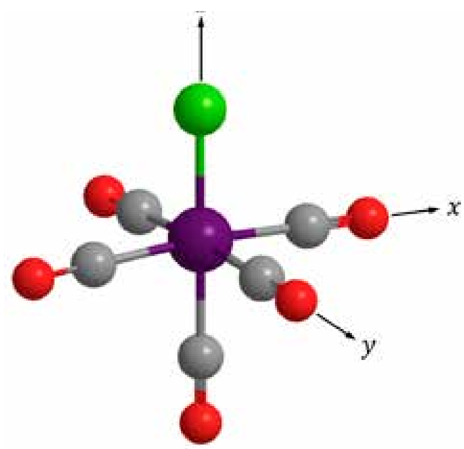

Fig. 2: Molecular structure of Mn(CO)5Cl. The central (purple) atom is Mn, the top (green) atom is Cl, and the other ligands (gray and red) are CO fragments. Image created using Chem3D software (PerkinElmer, Inc.)

These definitions may be best understood by using examples. Fig. 1 depicts the Eiffel Tower, and Fig. 2 shows the molecular structure of $Mn(CO)_5Cl$. These two objects have little in common except symmetry. If we observe the Eiffel Tower from a fixed position, then move 90° clockwise and view the tower again, it appears the same. The Eiffel Tower possesses symmetry because it appears unchanged under an altered view. Alternatively, we can rotate the Eiffel Tower by 90° counterclockwise and create a configuration that is indistinguishable from the original; its appearance is preserved under 90° rotation. Rotation by 90° is a *symmetry operation*, and the axis running vertically down the tower is the *symmetry element* about which the operation was performed.

The tower is said to possess four-fold *proper* rotational symmetry. An *n*-fold proper rotation is a 360°/*n* rotation; a two-fold rotation is 180°; a three-fold rotation is 120°, etc. A proper rotation is symbolically represented as C_n, the subscript indicating the rotation angle; therefore, the tower possesses C_4 symmetry. Suppose we cover our eyes while the $Mn(CO)_5Cl$ molecule is rotated by 90° through the vertical axis. In that case, we will find the altered object indistinguishable from the original when we look again. It possesses the exact four-fold rotational symmetry (C_4) as the tower.

Mirror planes are other symmetry elements common to both objects. A plane that includes the vertical axis and runs through two opposing legs of the Eiffel Tower reflects one half of the tower into the other. The resulting reflection (symmetry operation) is performed through the mirror plane (symmetry element). A mirror plane that runs through the remaining legs and includes the vertical axis (perpendicular to the first mirror plane) also exists. Two more mirror planes exit; those that bisect the legs and include the vertical axis and are orthogonal to each other. The same mirror planes exist in $Mn(CO)_5Cl$ and can be defined as the *xz*-plane, the *yz*-plane, and the two orthogonal planes that bisect the *x*- and *y*-axes and include the *z*-axis. Mirror planes are represented by σ, and a subscript can clarify the plane based on the object's orientation in a Cartesian coordinate system. As depicted, $Mn(CO)_5Cl$ contains a σ_{xz} symmetry element. Non-examples can be equally informative. The *xy*-plane in $Mn(CO)_5Cl$ is *not* a reflection plane. Although it reflects all the atoms within the plane into themselves, it moves the top (green) Cl atom where the bottom CO fragment is, creating a distinguishable configuration.

Finally, *improper* rotations are rotations that contain a reflection. *Proper* rotations can be physically performed (for example, our four-fold *proper* rotation of the Eiffel Tower). *Improper* rotations are abstract operations that can only be imagined. An improper rotation is rotating an object's mirror image or rotating while turning inside out. Because of its seams, a tennis ball has four-fold improper rotational symmetry. Symbolically, improper rotations are represented by S_n. The tennis ball has S_4 symmetry.

The set of all such transformations that leave an object (Eiffel Tower or $Mn(CO)_5Cl$) invariant under change is encoded mathematically into the symbolic language of group theory. This is a systematic method of describing the symmetries of objects by analyzing their transformations under certain operations. There are five symmetry operations (symbolically represented as E, C_n, σ, i, and S_n) carried out with respect to four symmetry elements (proper rotational axis, mirror plane, inversion center, and improper rotational axis). The collection of symmetry operations that an object possesses can be expressed as a *point group*.

A mathematical group is a collective way of describing something. A group is an enclosure whose interior contains elements that have a defined relationship with each other. The symmetry operations of an object, the collection of actions that transform the object into an indistinguishable version of itself, form a mathematical group. Group theory defines the internal consistency of elements. This internal structure can create resemblances to objects with the same point group. For example, one can learn about $Mn(CO)_5Cl$ by studying the symmetry properties of the Eiffel Tower. Classification of objects in terms of their point groups is an essential first step toward understanding their symmetry properties. This formalism has been a powerful organizing tool in many branches of science, including chemistry. Symmetry and group theory are central themes in Chem 41443, impacting almost every topic during the semester. They are also important in Chem 11181 and 21284, although the level of theory is less rigorous.

Student Engagement and using the Museum as the laboratory

While the Eiffel Tower is a suitable model for learning symmetry elements and operations, the most effective way to learn symmetry and point groups is through direct experience and hands-on activities. The premise of the museum visit to study symmetry is the hypothesis that communicating concepts in symmetry through art creates deeper learning than can be attained through the methods in a typical symmetry lab. These include viewing images on paper or screen or experimenting with molecular models.

Students' interaction with art in a museum creates sensory experiences that sharpen their visual imagination. At the undergraduate level, students are still more familiar with works of art than with molecules because of the arts' closer relationship to their everyday experience. The immediate encounter with art objects enables students to create a mental image of the object from the perspective of symmetry. The encounter inspires a visual memory of the patterns of formal symmetry.

It is proposed that the arts simultaneously trigger multiple cognitive processes of the brain that can extend openness to learning in other contexts (TYLER 2012). The process of science and the experience of art both involve thought experiments, so cognitive openness in one can spread into the other. Integrating science with art liberates the mind to construct a new comprehension out of overlapping thoughts. Knowledge attained in this way shapes students' learning, making ideas more accessible and permanent. Joining seemingly remote ideas into one has been posited as a defining element of creativity (KENETT 2014, 1018). Exposure to art as a way of learning science aims to draw on such a unity of creativity.

In conjunction with the systematic study of symmetry in General Chemistry and Advanced Inorganic Chemistry courses, I designed an activity in which students were asked to identify the symmetry properties of a group of paintings, sculptures, and cultural artifacts at the Snite Museum of Art. I worked with Bridget Hoyt, Curator of Education, Academic Programs, to select appropriate artwork and to coordinate class visits to the museum. I asked students to find objects from different historical ages and cultures, identify their symmetry elements, and answer some questions about them.

The museum visits were structured to allow students to design their own experiences. Students worked independently or in groups and could browse collections in any order and at their own pace. The lab handout and video pointed them to the artwork they had to interact with. Beyond answering the handout questions, students were encouraged to speculate on the artists' use of symmetry. Additionally, students were free to visit any part of the museum and engage with works of art they found interesting. The typical lab period for the museum visit was around two hours. During this time, my teaching assistants and I circulated through the museum, joining group discussions, prompting students with ideas, or answering questions. The visits were designed to promote interactive, collaborative, and student-centered learning with instructor guidance.

Students practiced systematic symmetry classification by applying the essential test of invariance under transformation to artworks in the museum. Exposing students to many examples gives them a mechanism for forming an understanding of the topic and gaining deeper insight into symmetry as a relationship of parts to the whole. By observing examples of artwork that contain C_2, they construct an intuitive understanding of two-fold symmetry. In a sense, they learn the group meaning by seeing many examples of elements that fall into a group.

The type of question that students were asked can be illustrated by two examples. First, students were prompted to identify the symmetry operations and assign the point for the *Falcon Basetripod with Glass Bowl*, as shown in fig. 3. This piece has three-fold proper rotational symmetry with respect to the vertical axis and three mirror planes that bisect the falcon wings and contain the vertical axis, so it has E, $2C_3$, $3\sigma_v$ symmetry elements, and belongs to the C_{3v} point group.

In a second example, the symmetry of a plate designed by Augustus Welby Pugin (fig. 4) depends on the observer's gaze. With a 'coarse' view, ignoring the details of the leaves and acorns, the symmetry elements are E, C_8, $8C'_2$, i, S_8, S_4, σ_h, $4\sigma_v$, $4\sigma_d$ and the point group is D_{8h}. When considering the details of the plate, the i, S_8, S_4, σ_h, $4\sigma_v$, $4\sigma_d$ symmetry elements vanish, and the new point group is D_8. In the 'fine-grained' view, the acorns and leaves bend in the same direction giving the plate a clockwise turn. With the decorations of the leaves and acorns, the plate descends from a higher to a lower symmetry.

Pugin was an influential Victorian architect, designer, artist, and passionate Gothic revivalist. He is perhaps best known as the designer of the Elizabeth Tower of the Palace of Westminster in London, England, colloquially called Big Ben. (The plate in fig. 4 is one of the rare Pugin pieces in any American collection.) Many cultures associate the oak with strength, virtue, and courage. In Victorian jewelry, vessels, and dishes, acorn adornments symbolized lasting love, stability, and prosperity. However, the directionality in Pugin's acorns and leaves creates a fluidity uncharacteristic of the pointed, rigid Gothic style. In our class visits to the Snite, students have remarked on the illusion of movement in the decorative acorns and leaves. This apparent contradiction of styles became a discussion point among students, leading to a few imaginative (sometimes anachronistic) interpretations.

Fig 3: Edouard-Marcel Sandoz, *Falcon Base Tripod with Glass Bowl*, ca. 1930. Bronze and glass. Raclin Murphy Museum of Art, University of Notre Dame, Gift of James W. and Marilynn B. Alsdorf, 1984.034.011

Fig. 4: Augustus Welby Northmore Pugin, *Plate*, 19th century. Ceramic. Raclin Murphy Museum of Art, University of Notre Dame, Gift of Ivan Thunder, 2007.012.002

This point illustrates the unexpected outcomes that arise from mixing art and science, particularly when these activities liberate students to explore the deeper meaning of works of art. The scientific definition of symmetry corresponds with symmetry as an element of form in art, arising from the harmony of proportions or balanced arrangement of parts. The lack of symmetry, or even the reduction of symmetry, can be equally meaningful. As in science, symmetry can illuminate deeper connections between parts of an artwork or the ideas behind it. Conversely, many students remarked that observing and describing the symmetry properties of works of art clarified some abstract concepts of formal symmetry and point group classification.

Two additional examples of works students have worked with at the museum illustrate how the symmetry of a molecule is connected to its physical and chemical properties.

Fig. 5: John Bisbee, *Spool*, 1992. Welded four-inch brads. Raclin Murphy Museum of Art, University of Notre Dame, Mr. and Mrs. Robert S. Nanovic, ND ’54 B.S. Fund, 2011.005

Fig. 6, from left: Unknown German artist, *Birdcatcher*, 17th or 18th century. Bronze. Raclin Murphy Museum of Art, University of Notre Dame | Giambologna, Birdcatcher, 16th–early 17th century. Bronze. Raclin Murphy Museum of Art, University of Notre Dame, Gift of Helen M. Scholz, 1993.082

Spool by John Bisbee (fig. 5), a sculpture of welded four-inch nails that stands as high as a dresser, has the symmetry elements C_n, C_{nv}, and C_s and belongs to the $D_{\infty h}$ point group. A molecule with $D_{\infty h}$ symmetry is non-polar, meaning there is no overall charge polarization in any direction. A polar molecule has an uneven charge distribution, while a non-polar molecule has an even charge distribution. A molecule must have an asymmetric charge distribution to be polar and possess a permanent dipole moment. The molecule’s point group determines whether it can have a permanent dipole moment and in which direction(s) it may point. There are only certain point groups that are polar, and the polarity of a molecule cannot change by any rigid rotation. Students are asked to reflect on the *Spool* and determine the symmetry elements required for an object (molecule or sculpture) to be polar. They are asked to justify their reasoning by sketching altered versions of *Spool* that would render it polar.

Polarity has consequences on chemical properties, such as the interaction of molecules with neighboring molecules in solution and their orientations in solids. Polarity plays a significant role in bonding between atoms in a molecule as the degree of polarity (corresponding to differences in electronegativities) contributes to bonding strength. Finally, polarity is involved with the interaction of a molecule with light, the basis of molecular spectroscopy.

Another important example of symmetry in chemistry is chirality. Chirality is a symmetry of mirror image objects that are not superimposable. Each mirror image object is referred to as an *enantiomer*. A pair of enantiomers are non-superimposable mirror images. Thus, mirror symmetry provides a test for chirality. If the mirror image of an object cannot be reoriented to be identical to the original, then it is chiral. Otherwise, it is achiral. The right hand is an inverted image of the left hand, so a right-handed glove does not fit on the left hand. The only way to make a right-handed glove fit on the left hand is to turn the glove inside out or invert it *through* itself. The term chirality is derived from the Greek word *χειρ* (cheir) meaning *hand*, and enantiomers of a molecule are said to have left- or right-handedness. As with polarity, chirality is a fundamental quality of an object because of its symmetry properties.

An *improper* rotation is a rotation in a mirror world, so an object possessing an improper rotational axis can flip through itself to create a superimposable mirror image. Therefore, symmetry classifications provide another test of chirality: a chiral body does not contain any *improper* rotational axes (but it may contain *proper* rotations). An object with improper rotational symmetry can flip through itself to create an indistinguishable mirror image.

Chirality is among the most fundamental aspects of the three-dimensional structure of molecules. In nature, the precise spatial arrangement of atoms in molecules creates very specific three-dimensional structures that are often chiral. This can dramatically affect the properties of chiral molecules whose interactions with other molecules may be restricted by symmetry. For example, biologically active molecules are often chiral. Therefore, chemicals designed to interact with them necessarily need to possess chirality. The lock and key metaphor for receptor-substrate complementarity is applicable here. If the lock is chiral, only one enantiomer of the key will fit.

In art, chirality is a way to illuminate the asymmetry of space and to connect art to philosophical inquiries into the natural world or beliefs about the interior world. The two bronze statuettes in fig. 6, replicas of *The Bird Catcher* by Giovanni da Bologna, are non-superimposable mirror images of each other. In each case, the artist chose the handedness of a sculpture, the same way that a chemist decides to use one of a pair of enantiomers as a drug candidate. The mirror is a powerful metaphor in the art and literature of many cultures. The reversal of space in chiral objects is an element of form that can create symbolic expression.

In a meditative ceremony known as Sema, Sufi Dervishes whirl in a ceremony that combines dance, music, and poetry. A mystical experience between lover and beloved unfolds as the Earth and spirit, the father and the mother, are connected. In Sema, the dancers always whirl anti-clockwise when viewed down the rotational axis of the spin. This left-hand turn, the counterclockwise turn, represents the quest for wisdom that goes through the soul (left) to reach the world (right). The bond between the spirit and the world has a directionality or handedness. A right-handed (clockwise) whirl would, in turn, represent a journey into the world to seek the spirit. The latter may represent Hegelian materialism, where self-consciousness travels through the perceptible world to reach the spiritual one. Two contrasting views of existence can be expressed as non-superimposable mirror symmetries.

Another example from a typical museum visit is the analysis of the symmetry properties of kinetic objects, such as George Rickey's *Triads*, (fig. 7). Symmetry transformations embody the idea of change and sameness. A transformation changes the object but leaves its symmetry unchanged. A kinetic object's structure transforms if its internal parts move with respect to each other, so its symmetry changes. This situation resembles fluxional chemical bonds, those that are free to change. For example, at room temperature, the energetic barrier to rotation around the central carbon-carbon bond in ethane is very low. At any instant, a collection of ethane molecules will contain an ensemble of different conformations.

Two such conformations and their point groups are shown in fig. 8. The ethane on the left is referred to as eclipsed. In this conformation, the C-H bonds of the two carbons are aligned when looking down the three-fold rotational axis that includes the C-C bond (the HCCH dihedral angle is 0°). The ethane on the right is referred to as staggered because the C-H bonds on each carbon are not aligned relative to the rotational axis of the C-C bond (the HCCH dihedral angle is 60°).

Fig. 7: George Rickey, *Triads*, 1958. Stainless steel and brass. Raclin Murphy Museum of Art, University of Notre Dame, Gift of the George Rickey Foundation, 2009.064.012

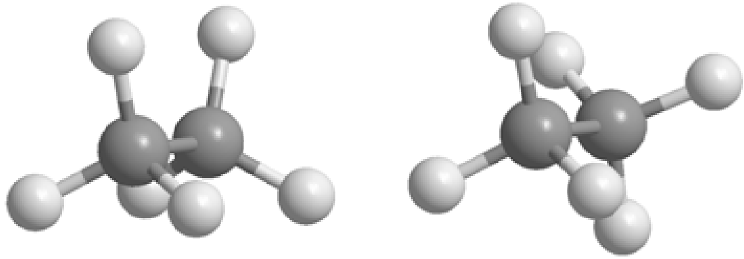

Fig. 8 (right): D_{3h} and D_{3d} rotamers of ethane. Image created using Chem3D software (PerkinElmer, Inc.)

The top and bottom parts of the Rickey mobile are free to move separately, creating altered conformation of the sculpture. These conformational changes are a model for understanding the dynamic behavior of ethane. The observer has to assign a point group to a static structure, a snapshot of a moment, because the symmetry of the objects acting as moving machines changes. One can reflect on the Rickey mobile as a representation of the transience of life or the role of chance in the world. Over a long period of time, the mobile will assume every possible conformation and repeat itself, perhaps reminding the viewer of the circular nature of existence. The same insights are possible for the ethane molecule, where a Boltzmann distribution of conformations is created at any given temperature. Here, the macroscopic view of a collection of ethane molecules appears unchanging with respect to time, whereas, on the microscopic level, the conformations undergo rapid interconversion.

As a challenging exercise, I ask my students to consider the symmetry properties of the Kenneth Snelson sculpture *Maquette for Mozart I* (fig. 9). This piece has no symmetry, but it does inspire students to think deeply about the relationship of parts to the whole. In their study of symmetry and group theory, students are introduced to the concept of group representations. A representation is an isomorphism, a mapping from one group to another that preserves the underlying group structure. A representation is not an analogy but a way of constructing and understanding the elements of one group by analyzing the elements of its representation. Representation theory is a way of translating questions about one group into questions about another. My interpretation of *Maquette for Mozart I* is that it is a representation of the atom. This sculpture exemplifies a *tensegrity* structure, a contraction of tension and integrity, where compression rods are fixed in a network of cables in tension. The structural integrity of the sculpture is maintained entirely through internal forces and does not depend on external parameters. In my view, *Maquette for Mozart I* describes the balance of forces within the atom. Quantum mechanics obliterated any pictorial view of the atom. Without any image of the atom, we can construct representations to help us understand the inner workings of the atom.

Fig. 9: Kenneth Snelson, *Maquette for Mozart I*, 1982. Brass tubes and wire. Raclin Murphy Museum of Art, University of Notre Dame, Gift of Thomas T. Solley, 2004.030

Art as a representation of ideas in science can clarify complex concepts and hopefully help the student connect ideas. The *Mozart I* sculpture is not a picture of an atom but contains the ideas that make up our thoughts about the atom. In human endeavors (science or art), there are moments when something appears to the observer to function differently than intended, and that different way becomes a new function. Snelson incorporated the balance between forces of nature into his sculpture but did not form an image of an atom. Isomorphisms, implied or imagined, play a role in understanding science through art.

The experience of studying symmetry in the museum places students outside their comfort zone. That's the point, but is it useful? Student feedback has been very positive, with many students remarking that understanding principles of formal symmetry through analysis of artwork in the museum was effective and enjoyable. Some students commented that the visual experience helped them understand the relationships of parts of an object to each other in ways that words had not been able to. In particular, training the eye to imagine objects under altered scrutiny (rotations, reflections, etc.) was a key takeaway from this activity. Overall, students valued their experience and came away with a positive feeling about their learning.

Based on conversations with students and observation of their interactions with each other, I draw another conclusion. After the museum visit, students were more comfortable using the language of symmetry. They communicated ideas of symmetry in a more straightforward way and with a greater level of authority. Symmetry is a powerful tool for predicting the physical properties of molecules and crystals. It is essential to be able to communicate these ideas before taking on more complex aspects of the topic. Learning in the museum appears to promote creative thinking and expression.

Finally, students commented that the freedom to explore at their own pace and against the backdrop of the artwork in the museum fostered a richer learning environment. I believe this is evidence that the atmosphere within the museum heightens students' intellectual and emotional awareness. Based on qualitative feedback, it appears that the art museum environment amplified students' creative process and deepened their engagement with the subject matter. In addition to thinking about symmetry, students exchanged ideas about the art, expressed their thoughts about the historical and social significance of the artwork, and debated the meaning behind some of the more challenging pieces. I conjecture that this kind of divergent thinking enhances creativity and communication about symmetry and is, therefore, more effective than the specialized instruction of a traditional curriculum.

Conclusion

As these examples illustrate, my use of the museum in teaching chemistry is based on a constructionist view of learning. For instance, students incorporate new knowledge about symmetry into their existing learning from traditional lectures. By comparing a new view of the material against their prior knowledge, they refine their thinking to link to the two and gain more profound clarity of the topic. This approach to learning empowers students to be independent thinkers and curious inquirers. Creative exercises, such as visits to the museum, are a tool to illuminate prior knowledge and allow students to incorporate new knowledge into their understanding of the world. When students' inner experiences about art are connected to their classroom learning, they acquire knowledge with more joy, making it more likely to become permanent. The effect that the teaching environment itself has on student learning is another design aspect of this project. While I do not have any assessment data, anecdotal evidence from my experience over the past seven and a half years strongly suggests that being in a museum helps learning.

Student feedback from their experiences with learning chemistry through art has been very positive. Many students remarked on how observing and describing the symmetry properties of works of art had clarified some of the abstract ideas of formal symmetry and point group classification. Some took advantage of the museum visit to go beyond the narrow experience of the symmetry elements of the artwork and to think more broadly about art. Others were delighted to discover that their prior belief in the connection between art and science was validated.

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Teaching Neuroscience in the Art Museum

Sarah C. Petersen and Jodi Kovach

Neuroscience is an interdisciplinary field that investigates chemical and cellular foundations for perception, emotion, and memory. At Kenyon College, these concepts are reinforced through class sessions at The Gund, Kenyon's teaching art museum, in both lower- and upper-level courses within the Department of Neuroscience. Students explore the neurological basis of visual processing through analysis of abstract works in The Gund's permanent collection. Using guided inquiry, students explore color's nonobjective properties, the variability of these properties based on context (color consilience), how color and color combinations imply or express textures and surfaces, and why color is often used as a metaphor for emotion. Our class sessions, refined over several semesters, reinforce principles discussed in didactic neuroscience lectures and elicit productive intersections between art and science. By upholding the rigors of scientific inquiry within the gallery, we have centered the art museum as a place for interdisciplinary study.

Visual perception is the process by which the surrounding environment is interpreted via sensation of light. In humans and other animals, visual processing begins with light focused on photoreceptive cells in the retina of the eyes. This signal is transduced to specific brain regions for processing and perception to build our visual sense of the world. Mechanisms driving visual perception are typically taught in neuroscience and psychology courses; however, these principles are also important for understanding how our brains organize the visual elements of a work of art. Both visual processing and visual analysis of art can be reduced to foundational concepts of line, color, and form (ARNHEIM 1997; KANDEL 2016).

Research has shown that the art museum can serve as an informal sector for scientific education, complementing traditional classroom and laboratory settings (STOCKLMAYER 2010). Educational approaches to teaching STEM with and through art can involve displaying specific concepts in an artistic way to communicate more effectively to a lay or secondary school audience. Collegiate educators have also assigned students the task of drawing as a means to visualize challenging biological and neuroscience concepts through illustration (EZIN et al. 2020; GOODSELL 2021). However, we believe the art museum can also be a venue for experimentation through guided observation of, and discussion on, works of art—carefully planned and moderated by the collaborating neuroscience professor and museum educator. In this way, neuroscience students can interrogate core principles through analysis of art that in itself does not intentionally represent or teach a neuroscience concept but can offer compelling and challenging ways of engaging with course content.

Student-centered guided activities in the art museum provide an opportunity for active learning, which has distinct advantages over the traditional classroom-based lecture (FREEMAN et al. 2010). Active learning methods create opportunities for collective exploration and discussion, questioning of knowledge, and critical application of learned concepts. Importantly, active learning pedagogies disproportionately improve outcomes for minoritized students as well as first-year students (FREEMAN et al. 2010; STYERS et al. 2018). Furthermore, active learning via art analysis in the museum has been shown to improve engagement and critical thinking with biology students (MILKOVA et al. 2013).

We therefore decided to bring students in neuroscience courses to The Gund, the teaching museum of Kenyon College, a small liberal arts college in rural Gambier, Ohio. To explore and reinforce principles of visual perception, we designed two activities tailored to different neuroscience courses at Kenyon. Activity 1 links across different sensory systems for the introductory neuroscience course (200-level), whereas Activity 2 explores principles of retinal wiring in the upper-level neurobiology course (300-level). We have run each activity in at least two semesters with different populations of students. Below, we present the learning goals for each activity, including the core concepts for students, followed by the mechanics of the activity including guided prompts. Finally, we describe the students' responses, which demonstrate the effectiveness of the activity.

Activity 1: Connecting Neuroscience Concepts in the Museum

Learning goals and core concepts: At Kenyon, the neuroscience course is offered at the 200-level as the 'on-ramp' to the major, typically following 100-level biology and chemistry courses. This course combines survey of subfields with foundational principles, such as structure-function relationships. Students learn neuroanatomy and major regions of the brain early in the course with a cursory function assigned; for instance, the occipital lobe at the back of the human brain processes visual information, while the hippocampus nearer the front is largely responsible for memory. Throughout the semester, students recall these structures in more thorough discussion of different sensory systems, behavior, emotion, learning, and memory in both healthy and dysfunctional states (e.g. neurological disorders, mental illness, etc.). Ultimately, the course material emphasizes how human perception is influenced by multiple sensations, memory, and emotion.

However, while this discrete topical approach to neuroscience works well for organizing course material, it can lead to compartmentalization. Students sometimes fail to understand or appreciate how these systems connect into complete brain function; for instance, how visual cues can prompt nonvisual responses or suggest information that is not supplied but rather 'filled in' through experience. Given the emphasis on neuroanatomy and structure-function, students might then suppose that different regions or physical connections in the brain (structures) are important for these emergent experiences (function).

Therefore, we created an activity in the museum with the goal that students would integrate their understanding of sensory systems, emotion, and memory in response to visual art. Students would be tasked with applying their knowledge of sensation at the level of receptors, circuits, and perception, which tend to be less variable between individuals, with the modulatory mechanisms that drive memory and emotion, which are likely to be more subjective. Because this is quite broad for introductory students, we invited the students to focus primarily on color, which is a relatively simple way to illustrate how context influences perception.

Activity structure: As noted above, this activity asked students to integrate their understanding of multiple sensory and behavioral systems; as such, we carried out this activity relatively late in the semester, typically in the eleventh or twelfth week of instruction (out of fourteen). Students visited the museum as a group during the class time. Prior to class, students were assigned a review article on color consilience by neuroscientist and visual artist Bevil Conway (2012). This article integrates core neuroscience topics discussed in our class, such as wiring of the visual system and color perception, with applications to art in color and form.

When viewing pieces, students were encouraged to focus on color and other visual cues, such as arrangement of elements, negative space, and visible texture. We worked with four to six artworks for classes of eighteen to twenty-four students, which allowed students to interact closely with the art. We chose abstract pieces to help the students concentrate on formal elements (color, line, shape, space, pattern) rather than subject matter. With an abstract painting, students cannot interpret the artwork iconographically or symbolically; freed of this 'distraction,' they can direct their attention to how our perceptual faculties process color, and how the painting, as an organized set of visual stimuli, triggers sensory systems.

Fig. 1: Pia Fries, *Caluori*, 2001. Oil on board. Collection of The Gund at Kenyon College, Gift of David Horvitz '74 and Francie Bishop Good, 2019.3.2. © 2024 Artists Rights Society (ARS), New York / VG Bild-Kunst, Bonn

Caluori (fig. 1), an abstract oil painting by contemporary artist Pia Fries, is a particularly strong example of the work that we have used for this activity. Color is the primary structuring agent in *Caluori*; variations in hue, value, and saturation create the perception of depth on the flat surface. Juxtapositions of colors generate what we see as movement in the form of turbulence, sweeping arcs, swirls, and broad, still passages of modulated whites. Moreover, the exuberant colors in *Caluori* seem to ooze and protrude in viscous swaths and mounds of paint over foamy washes. We can leverage the artist's vigorous application of paint to help draw out associations in our perceptual processing of color and texture, which makes the colors themselves seem almost palpable, conjuring visceral and haptic responses.

Class sessions were led by the museum educator in the art museum, who moderated the discussions with the neuroscience professor. Following a brief introduction to the artwork and the activity, students paired off to view and discuss a single piece of artwork in their small groups. Students were guided in independent discussion by addressing the prompts provided by the instructors (table 1). These prompts required students to reflect on the pre-class reading and their own experience in the museum.

PROMPT	GOAL
1. Stand closely to the piece; choose a color and describe its tone and hue. Focus on one section of the composition, then find the same color in a different section, where it is surrounded by different colors, and analyze it again. How does that relate to the ideas in the assigned Conway paper?	Recall the pre-class reading; identify contextual influence of color perception
2. Look at a few different color combinations. What are the temperatures of these colors? How do you think they taste? Can you imagine their smells?	Articulate how visual information can connect to other sensory systems
3. Describe any emotional experiences you have while viewing this artwork. Does it evoke a constant state of feeling? Do different emotional moments arise as you visually process the colors? Could different sections of the piece elicit different feelings? Why?	Apply visual information to other major brain systems; identify and appreciate subjectivity in perception

Table 1: In-class prompts and associated pedagogical goals for connecting concepts across neuroscience systems

Following the museum class session, students used their in-class notes and discussion to craft short essays of two to three paragraphs (table 2). These essay responses were part of regular engagement on our learning-management system (Moodle). Unlike the in-class materials that narrowly focused on the present assignment, these prompts asked students to synthesize their ideas from the museum with previous class materials. Students could draw on their knowledge of basic neural function and neuroanatomy and/or applied understanding of sensory, behavior, and memory systems to address the prompts, depending upon their reported experiences in the museum. Students were given narrative feedback from the instructor on their ideas and how they connected their experiences to other parts of the course. Because the prompts encouraged speculation, students were assessed on their creative application of didactic lecture material to the subjective experiences in the museum, rather than on obtaining a 'right' answer. Most students fully met or exceeded the instructor's expectations for engagement and application.

PROMPT	GOAL
1. What visual aspects seemed linked to other sensations or emotions? Were these connections universal, or subjective depending upon the individual?	Recall and describe the in-class activity, with emphasis on question 3 (Table 1)
2. Make a few predictions about how these co-incident sensations and emotions could be due to functional connectivity in the brain. Be sure to speak to particular brain regions, circuits, and/or neurotransmitters, etc. that could be responsible for evoking sensations and emotions from a visual experience.	Apply prior knowledge of neuroscience systems to their particular experience in the art museum

Table 2: Short essay prompts and associated pedagogical goals for connecting concepts across neuroscience systems

Student outcomes: During the class activity, students typically focused on color, contrast, and form in the pieces to discuss visual observations as well as connections to other senses. As expected, many students drew from their knowledge of the lecture materials on vision, emotion, and memory in the initial discussion, reinforcing concepts from earlier in the semester. However, several students also recalled their experience and training in other disciplines, including art history, anthropology, and psychology, to frame their observations and provide reasoning for their conclusions. Because every partner pair was called upon to report their observations by going around the room, students had the opportunity to hear and report similar and differing perspectives, so the discussion was not limited nor biased to a few students' experiences. This strategy is aligned with best practices in the STEM classroom, in which carefully structured discussions are critical to promote equity among students of different backgrounds (EDDY et al. 2017)

Importantly, the instructor noted a difference in engagement for some students; many of those students who had previously been 'quieter' in the regular classroom spoke at length during this museum activity and took on a leadership role in conversations with other students. This was noted for students who were, or soon would be, majors in the Neuroscience Department, as well as those in other majors in and out of the natural sciences; therefore, this heightened engagement was from students across disciplines. Volk and Milkova describe this shift in classroom dynamics as one facet of the "productive disruption" that occurs during the curricular museum visit. They point out that because museums are settings in which behavior is influenced by contextual factors, the social dimensions of the class visit should also be considered, along with cognitive assessments, in evaluating the learning benefits. The reorganization of social conduct in the classroom occurs, in part, by defamiliarizing the setting, or the 'crossing' from classroom to museum gallery, which conditions the students for learning in new or different ways. Nevertheless, the cognitive gains of such reorganized social dynamics can only be achieved through a well-planned visit, which is structured to focus students' attention on the intersection between course content and the artwork (VOLK & MILKOVA 2012).

Because this activity asks students to start with a comparison of common vs. different experiences, the post-activity essays often had a different starting point as well. For instance, students reported both positive and negative associations with the same red abstract form (e.g. fragrant flowers vs. bloody river), and accordingly linked these to either pleasant or somber emotions. Students were able to explain how associations were likely based on memory, emotional state, or both, and were able to discuss brain areas (e.g. hippocampus, amygdala, ventral tegmental area) and neurotransmitter systems (e.g. serotonin, dopamine) that would likely be associated with these perceptions. Therefore, students could apply this interrogation of their experiences to core concepts of the course. This cycle of observation, application, and prediction is the foundation of experimental science. Even though students did not actually test their predictions, they nonetheless applied laboratory skills in the art museum.

Activity 2: Connecting Neurobiology Concepts in the Museum

Learning goals and core concepts: The visual system in humans is complex, yet relatively well-defined at the cellular and anatomical levels. From decades of experiments in animal retinas, scientists can predict how different visual stimuli activate certain cells within the retina and how these cues are relayed to the cortex (information-processing part) of the brain. The details of how this circuitry drives perception is taught in Kenyon's 300-level neurobiology course; a simplified version of this system is shown in fig. 2. We teach these concepts for two reasons. First, this system is fundamental for understanding visual processing specifically and topics in perception, such as receptive fields, more generally. Second, the architecture of the retina can serve as a more general framework for approaching key topics in neuroscience, such as how neurons receive sensory input, how they send signals in response, and how this impacts the animal's experience.

These complex and detailed concepts are challenging to grasp in a traditional class format, even with student-led discussion and practice; therefore, students can particularly benefit from experiential learning in this concept area to reinforce these ideas. However, scientific experiments and demonstrations for these concepts are technically challenging for students and are beyond typical institutional resources, including our own. Therefore, we designed a session in the art museum that allowed students to interrogate how spatial visual cues are mapped onto the retina and drive perception. Ultimately, the goal of the exercise was to reinforce knowledge of visual system wiring to discuss "why they see what they see." We chose to work with a series of abstract prints that are nearly identical in the application and arrangement of formal elements, and therefore require close, focused observation to discern how the unique color palette of each print causes us to perceive differences in composition from one to the next.

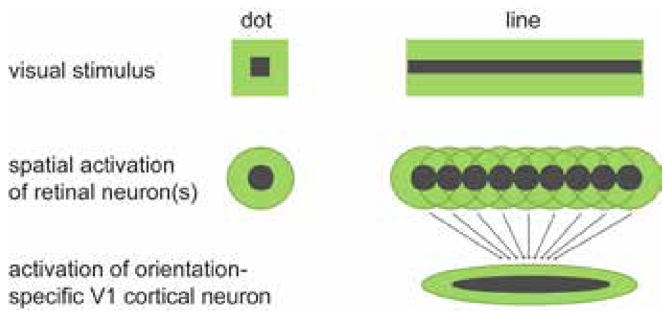

Fig. 2: Simplified framework for information flow during visual processing. Spatial elements in a field of vision (e.g. a dot or a line) activate signaling in specific retinal ganglion cells, which is transduced to the visual cortex to initiate perception. This example specifically illustrates receptive fields of off-center, on-surround retinal ganglion cells receiving input from rod photoreceptors.

Activity structure: Students enrolled in this course had already taken the foundational neuroscience course described above, and often they had some upper-level biology and chemistry training as well. At the point in the course in which we conducted the activity, students had already learned physical and chemical properties of the neural membrane and nerve conduction as well as synaptic transmission. Students could then apply these principles to systems and networks, starting with sensory systems. This activity was immediately preceded by two to three days of traditional class instructions (lecture and discussion) to experience and reinforce concepts of visual system wiring. Readings were primarily from the course textbook (NICHOLLS et al. 2012) and focused on seminal works describing retina structure and function (KUFFLER 1953; DOWLING & BOYCOTT 1966). Students also read or reviewed the same Conway review article (2012) from Activity 1 (as not all students had read it in the neuroscience course) to review color vision and begin to apply these principles to visual analysis of artwork.

Each time we have conducted the activity, we have used four prints by contemporary artist Amy Ellingson from her 2018 series titled *Identical/Variation* (figs. 3–6). In creating these prints, Ellingson took inspiration from the layered visual structures of computer-generated imagery. She then combined digital and traditional printmaking methods in a process that involved making an etching in black ink, printed from a plate created on a flatbed printer, of the circuitous linear pattern of one of her paintings, using it as the organizing structure for each print. After this, Ellingson manipulated each print with the addition of acrylic color and, lastly, a layer of laser-etched relief woodcut, printed in a series of four different colors—red, green, black, and blue, as the title of each print denotes. She shifted, slightly, the orientation and color of subsequent layers from one print to the next to reveal variations in the patterns, thereby expressing "originality within repetition." This "originality within repetition," or the ostensible compositional variations from print to print that Ellingson achieved through multiple printmaking processes, subtle shifts in the orientation of the underlying linear pattern, and changes in color, make the prints particularly ideal for this exercise: with focus, students can appreciate the repeating elements; however, this repetition is not apparent at first, which is largely due to differences in orientation and color/contrast. Therefore, students can interrogate these differences by first calling an individual element into their attention and either comparing it to another piece or literally shifting their own perspective.

Figs. 3–6: Amy Ellingson, *Identical/Variation*, 2018. Etching, UV acrylic, and woodblock relief. Collection of The Gund at Kenyon College, purchased with funds provided by Mr. and Mrs. Graham Gund '63. Courtesy Amy Ellingson and Eli Ridgway Gallery

As in Activity 1, students visited the museum during regular class time for the activity, which was led by the curator of academic programs. Following the introduction, students were placed in groups of two to three students and guided in discussion with prompts provided by the instructors (table 3).

Student outcomes: Working in pairs, students identified and discussed individual attributes that they could explore simply by moving around the gallery space. As an example, some students noted the arrangement of lines within a piece and recalled how visualization of lines of different orientation depended upon spatial activation of retinal neurons and subsequent activation of particular V1 cortical neurons table 1, question 1). They could then make predictions about how to change stimulation of V1 neurons and experiment with viewing angle and distance (table 2, question 2). We found that the placement and

PROMPT	GOAL
1. Study one of the Ellingson prints and recall the differences in receptive fields for neurons in the visual system. What features evoke responses in which cells? Consider contrast, lines, orientation, etc.	Recall the pre-class readings and course content to describe principles of visual receptive fields
2. Move around one print and note how your perception of the composition changes. How does the viewing distance or angle influence the features you identified in question 1? Similarly, how does the contrast, orientation, etc. of features result in differences in your perception?	Compare and contrast visual stimuli (before/after movement) as they project differently onto the retina and are therefore perceived differently
3. Now, examine other prints in the collection, and identify how a feature is repeated across at least two compositions (e.g. etching, woodcut print, etc.). How has Ellingson changed (or not changed) the feature across prints, and how does that influence your perception? In other words, how might "originality within repetition" arise based on visual connectivity?	Compare and contrast visual stimuli (different paintings) as they project differently onto the retina and are therefore perceived differently
4. Consider the role of color in your perception of these prints. Again, move around the prints and note how your perception of color changes from different viewpoints. How is color "wired up" in the brain, and how does that influence your perception across prints?	Compare and apply principles of color perception to those of contrast (e.g. dots, lines) to predict differences in perceptions

Table 3: In-class prompts and associated pedagogical goals for applying concepts in visual system wiring

orientation of the artwork impacted the students' 'experiments': in one semester, the artwork was hung on the wall, and students frequently chose to investigate distance; in another semester, the artwork was displayed flat on tables, and the students walked around the artwork to examine from multiple angles. For both types of 'experiment,' students explained why these perceptual changes were driven by the different projections onto the retina by considering the circuitry of the visual system. For instance, students could focus on horizontal lines at a typical angle or distance. However, when they viewed the piece at a steep angle or long distance, fewer retinal neurons could be activated by these lines; as a result, lines with lower contrast appeared to blur together into a single, relatively uniform shape. These findings are represented in simplified form in fig. 7A.

The "originality within repetition" of the Ellingson prints allowed students to interrogate differences in contrast and color. Because some elements are repeated across prints, students could identify 'control' vs. 'experimental' attributes; for instance, a pattern that was identical across prints but in a different color. Students found that color and contrast were sufficient to substantially change their perception of otherwise identical elements when testing viewing angle and distance (table 3, questions 3–4). Again considering only horizontal lines, students noted that light vs. dark contrast or color opponency affected their ability to interpret the elements at a steep angle or distance (fig. 7B). Students again were able to explain how these changes depended upon the initial activation of retinal neurons and the differential activation of V1 cortical neurons to ultimately alter their perception. Finally, by bringing groups together in discussion at the end of the class session, students were able to identify that different elements within the pieces were subject to changes in perception, while others were relatively stable.

Activity 2 largely demonstrated the commonality of experiences between students, in contrast to Activity 1, in which students identified subjective aspects of their experiences driven by memory and emotion. Because Activity 2 reinforced understanding of relatively stereotyped visual circuits, students rarely differed in their perception, though one exception was a student with self-reported red-green color blindness. However, altering the modality and location of learning about visual circuitry can promote both comprehension and retention of the material for students with different backgrounds. Additionally, students can quite literally see how the visual

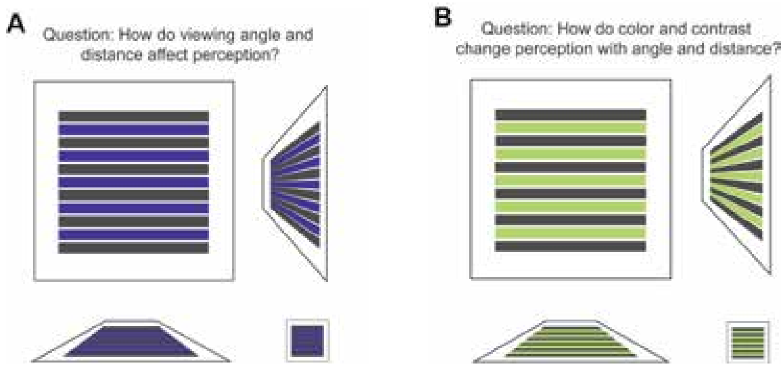

Fig. 7: Sample 'experiments' in visual perception. (A) Students focused on horizontal line elements in the artwork and observed how perception of lines persisted or disappeared based on viewing angle and distance. (B) Horizontal line elements in artwork with higher contrast color persisted even with different angles and distance, which students attributed to differential activation of retinal ganglion cells.

system can respond to relatively straightforward inputs, using stereotyped circuits, in complex and nuanced ways. Finally, while this activity is less open-ended than Activity 1, it nonetheless serves as an opportunity for experiential learning and application of concepts, similar to a laboratory exercise.

Discussion: The Academic Art Museum as Laboratory

Through testing and implementing the course activities explained here, we have observed that the art museum essentially becomes a kind of laboratory of inquiry-driven learning, exploration, and experimentation. In other words, by 'asking' students to produce information in response to the artwork, rather than imparting information through 'telling,' we created opportunities for collective exploration and discussion, questioning of knowledge, and critical application of learned concepts. The far-reaching learning benefits that the pedagogical model of active learning holds for STEM students was affirmed in a 2014 article published in the *Proceedings of the National Academy of Sciences* on active learning (FREEMAN et al. 2014). The primary objective of this study was to determine if active learning boosts examination scores and lowers failure rates. Data on instructor-written course exams and other assessments showed that students performed better overall, but there was more significant improvement, on average, in performance on assessments of students' conceptual understanding of a given subject. This could suggest that active learning stimulates cognitive processes that cultivate deeper, more nuanced understanding of course topics, which we observed in the activities described above.

A study by Milkova et al. assessing the outcomes of skill-development exercises for undergraduate biology students at Oberlin College (2014) supports our observations. The article gives insight into how and why implementation of artwork analysis yields higher learning outcomes and retention rates by drawing connections between gains in students' analytic abilities and data on whether or not students found the activities intellectually engaging, meaningful, and thought-provoking. Qualitative data showed that generally, the activity piqued students' curiosity and inspired collaborative work and critical thinking, indicating that teaching biology concepts through art can broaden and deepen students' ways of understanding and engaging with course material.

Students who most often fall behind in class appear to benefit most from active learning methods, which could suggest a means for achieving greater equity in STEM classes (FREEMAN et al. 2014). The results revealed that active learning improves undergraduate education and retention in STEM fields for all students, but especially for students from disadvantaged backgrounds and female students in male-dominated fields. Although the pedagogical methods in the Freeman study took just 10–15% of class time, the fact that they were an integral part of the class structure (rather than taking place outside of class) suggests that something about the classroom dynamics shifted as a result of active learning, to create the conditions for greater success among all students, especially among underrepresented groups.

Teaching with art, like most active learning methods, seems most effective in fostering an open, inclusive learning environment when communication among all students and instructors is possible. We have observed in the class sessions that we conduct in the gallery that engagement with the artwork creates the freedom to ponder, question, express uncertainty, and solve problems creatively and collaboratively, generating a shared communicative space. The nature of this learning moment is the topic of a recent essay on language learning in the art museum, in which the authors argue that engaging with the work of art stimulates radical forms of 'looking' that can ultimately lead students and instructors to think beyond hierarchical and institutionalized ways of acting and interacting in the classroom (KOVACH & RIEGERT, 2023). Based on course engagements with contemporary artwork that they had designed and tested for German literature students, the authors proposed that the aesthetic practice of foreign language and cultural learning, enunciated through engagement with artwork in the museum, creates an inclusive, open, and evolving learning environment that impels learners to interpret the art and course content from unlikely perspectives and through the eyes of others (RANCIÈRE 1991).

Active learning through engagement with art also changes the role of the museum in society from an institution that reinforces hierarchies of higher education to a public space for exploration, as Emily Pringle, Head of Research at Tate, has theorized in her book, *Rethinking Research in the Art Museum* (2020). Our work speaks to Pringle's call for exploring how the art museum can "engender an environment that fosters creative and critical enquiry and the formulation of new knowledge by the many 'experts' that come into contact with the institution, rather than a select few." This expanded notion of research can guide experimental pedagogical approaches in the museum that seek to reorder the dynamics of exchange and generation of ideas among students and instructors and to invite critical engagement with art from a diverse range of disciplinary perspectives.

Conclusion

The course activities described here offer two examples of how teaching neuroscience through art for college undergraduates can procure different ways of engaging with and understanding course content, inspiring rigorous application, complex synthesis, and critical questioning of important concepts. Our pedagogical approaches align with active learning methods and, as we have observed, have yielded the many benefits of teaching models based on 'asking' as opposed to 'telling'—not only strengthening students' mastery of key concepts but also cultivating a more sophisticated grasp of the intersection of concepts learned throughout the course. Teaching neuroscience through art transforms the art museum into a dynamic learning laboratory in which students can explore new ideas, take intellectual risks, and produce knowledge that can spark ongoing research.

STEM curricula at colleges and universities, like museum collections, vary among institutions; therefore every approach to teaching neuroscience with art will have an original character. Identifying provocative connections between works of art and scientific concepts invites the curiosity and creativity of instructors and museum educators in developing challenging and meaningful learning activities. Here, we have offered insight into how we have leveraged the unique formal qualities of specific artworks in the collection of The Gund to help ignite students' ability to bridge productive connections between art engagement and scientific thought. There is no formula for choosing the right work of art for a course activity; instead, the process involves a mode of creative, collaborative inquiry, a difficult exercising of our knowledge, departing from certain conventions of our different academic specializations, and the same intellectual risk-taking that we ask of the students. Our work together continues to fuel our curiosity and drive to understand how students learn and how to enable them to think beyond the knowledge we can share with them.

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college neuroscience education, sensory systems, art, active learning

The Messiness of Real-World Data: Using a Museum Database in a Computer Science Class

Hannah Wirta Kinney and Cynthia Taylor

This paper discusses an assignment where students in a computer science course compared data in the museum database to the physical objects in the collection it described. Through it students discovered big-picture issues in database design, including categorizing objects, keeping databases updated, and the impact of such decisions on an intended user. The assignment provided computer science students and museum staff insight into both the role of museum databases in structuring collections and the inherent difficulties of categorizing and curating information for a wide range of users.

Introduction

In this paper, we reflect on an undergraduate computer science assignment that explored the question "To what extent can data points capture the complexity of an object?" To answer it, students closely compared the object information held in the museum database with their experience of viewing those same objects in the galleries. Student responses independently brought up difficult real-world issues within database development and implementation, without the instructor presenting them beforehand. This assignment therefore offered an exciting opportunity for students to have firsthand experience with the messiness of real-world data using their campus museum as a lab.

The assignment was codesigned by the authors of this paper, an associate professor of computer science and a curator of academic programs, both of whom teach at Oberlin College, a small liberal arts school in the midwestern United States. The campus art museum, the Allen Memorial Art Museum (AMAM), has a collection of 16,000 objects representing 6,000 years of history and many cultures from around the world. The museum plays a central role in teaching and learning across campus by promoting object-based inquiry to explore essential questions, develop skills, and provide historical context. Most often this is done by using a select number of artworks to serve as case studies. This assignment instead turned the museum itself—both physical and digital—into the object of inquiry and analysis by drawing on the tools that computer science offers for observing, organizing, and analyzing large quantities of information. Issues of categorization and definition are known to be hard problems in database design and computer science broadly, with consequences for both users and data (ANDRE 2014; BOWKER & STAR 2000; SUCHMAN 1993). Dipping into the museum's data and thinking about its relationship to a single object ultimately provided a gateway for students to understand the challenges of confining the complexity of an object's visual and material presence within a series of database fields (BACA 2006). Furthermore, this assignment was an opportunity for students to critically consider how the database—a less visible tool of museum work than labels that are frequently analyzed by humanities courses—also contains categorical biases, influences curatorial narratives, and impacts how visitors can comprehend global art production.[1] Student responses to the assignment therefore revealed that inquiries into museological practices can be as productive and nuanced in computer science courses as they are in art history or history courses.

The computer science professor previously worked as a database programmer, giving her familiarity with database design in the software industry. This assignment moved students from the theoretical to the practical, offering a unique opportunity for students to independently discover key issues that arise when designing and supporting databases in the workplace but are rarely discussed in computer science courses. Working with information in the museum's database, as opposed to synthetic data crafted to neatly fit into database columns, allowed students to interact with both a real-world data collection and the physical objects described by the data. They thus saw databases as they actually exist: containing information that is difficult to categorize, missing data, and serving a variety of users with conflicting needs. Ultimately, this enabled reflection on the extent to which data fields—such as the Title or Dimensions—can describe an object in meaningful ways. Critically analyzing the decisions about what information should or should not be included in a database in turn revealed the impact of those decisions on potential users, giving students a more nuanced understanding of their future roles as database designers.

[1] The special issue of *Museum Anthropology* edited by Hannah Turner (2016) dives deeply into the relationship between museum catalogues and knowledge production.

Reflection on the tasks of categorizing, describing, and thinking about end users is fruitful not only for computer science students designing databases but also for museum professionals tasked with translating complex objects and their histories into datasets that can be used internally and externally. These shared concerns underline the importance of academic museums as loci of cross-disciplinary collaboration and learning by both students and professionals.

Overview of Course and Assignment

This assignment took place within an upper-level computer science elective, Computers and the Physical World. The course began with assignments looking at ways computers can represent the physical world, such as through data visualization and databases, and then spent the rest of the semester considering interactive embedded systems that observe and interact with the physical world. The museum visit occurred during the second week of the semester and was planned as an opportunity for students to think critically about the choices that are made in database design.

Before the students began their exploration of the database, they spent fifteen minutes engaged in a deep noticing exercise with Felix Gonzalez-Torres's *Untitled (Revenge)* of 1991, a work consisting of 325 pounds of blue candies in clear plastic wrappers that can be arranged at the discretion of the curator. In this instance, installed in an exhibition titled *Afterlives of the Black Atlantic*, the candies occupied a central rectangle of the gallery space that served as a visual metaphor for how the forced movement of enslaved Africans across the Atlantic linked the artworks in the exhibition (fig. 1). The moving, conceptual artwork offered a starting point for thinking about how the intentional choices of the curator in placing the candies within a particular structure shaped a visitor's experience of the artwork and connected it to other works in the gallery. This primed students to see the museum as full of decisions that influence how visitors can make and understand meaning.

Fig. 1: Felix Gonzalez-Torres, *Untitled (Revenge)*, 1991. Blue candies in clear wrappers, endless supply. The Felix Gonzalez-Torres Foundation, installed in the Allen Memorial Art Museum, Oberlin College, as part of *Afterlives of the Black Atlantic*, 2019–20

After this communal looking experience, the thirty students were divided into six groups. Each group was assigned a column of a comma-separated values (CSV) spreadsheet that had been directly exported from the museum's collections-management database (The Museum System, or TMS) with information about all of the objects categorized as currently on view in the galleries. The sheet included the following fields: Title, Materials/Techniques, Object Name, Dimensions, Credit Line, Classification, Period/Dynasty, and Culture (fig. 2). Though TMS contained other data fields, including previous label copy, these columns with shorter bits of information were selected because they would force students to think about how subjective, interpretative decisions were being made through the creation of this seemingly objective data and not only through curatorial choices and wall labels. Once provided with the CSV file and a laptop per group, the students spent one hour exploring the museum.

In the galleries they discussed the following questions, taking notes for a post-class reflection paper:

1. How is the art currently arranged? Pick two columns from the database that you think represent the current ordering/groupings of art within the museum, and explain why you chose them.

2. Imagine you are rearranging the art museum by your assigned column, instead of its current organization. Select ten objects that illustrate something about your column.

3. Have each member of your group pick a different piece of art. Compare the experience of looking at it with the information recorded in the database. What column(s) do you think are missing from the database? What would need to be added to fully capture the art? How was this illustrated in the pieces you looked at?

Fig. 2: CSV datasheet provided to students for activity

These questions encouraged the students to first think about how the overall museum was structured, then focus on a group of objects put into relationship by the database, and conclude by considering a single work. Moving from this large framework toward the individual object was intended to encourage students to contemplate how the database's overall structure creates a specific shape or form for the object's data to fit within. They were also meant to see that the overall database structure constructs relationships, intentional and unintentional, between objects. Thinking about these complex micro and macro relationships in the physical space of the museum offered a different perspective on the data fields than would be possible in a classroom or on a screen. Students were able to physically walk through and encounter firsthand the information contained in the museum database.

At the time of this class visit, the museum was primarily arranged along the classical 'encyclopedic' museum model, with objects by makers from the same or geographically close cultures displayed together. Temporal narratives were also at play in the installation. For example galleries of European art were arranged chronologically from ancient Mesopotamia to the late 19th century, where the modern collection began. Several groups even recognized that these organizing categories appeared on the maps they were using to navigate the museum. This allowed students to quickly perceive that the galleries reflected the columns of the database that contained information about Culture and Period/Dynasty. After this first realization, they could then see how arranging the entire museum by a single predetermined column, like Dimensions or Materials, would create an entirely different narrative. Through this task, the group assigned the Credit Line column noticed how much private collectors with specific agendas or interests might influence a museum's collection and how this might be better visualized by displaying objects from the same donor together. Having the students then select ten objects that revealed something about their assigned column also made them critically consider how decisions about which data would be collected could potentially impact a user or visitor's understanding of an object.

Discussion of Student Responses

As will be discussed below, having students think through these questions surfaced big-picture issues in database design that in previous courses the computer science professor had needed to explicitly spell out. The active- and inquiry-based learning opportunities provided by this assignment are in line with research-supported best practices for STEM in general and computer science in particular (FREEMAN 2014; THEOBALD 2020).

Categorization

Categorization is essential to database design: databases define tables of specific categories of objects and the fields associated with those objects. Additionally, fields within tables may include additional categorization to aid in searchability or provide information to database users. Because computer science is frequently pushing the boundaries of new technologies, computer scientists often find themselves tasked with making categorization decisions they may not have the expertise or training to make. Because these issues are not 'technical' and arise only in complicated real-world situations, they are rarely discussed in computer science coursework and are hard to provide concrete examples of without a sufficiently complicated yet accessible database. However, in viewing how the complex objects housed in the art museum were described within the database, the difficulty of categorization became apparent to the students.

A student commenting on an object in the database titled *Maiolica Apothecary Jar with Floral Decoration and Medallion of a Cherub and Trophies*, made of glazed earthenware and dated 1569 (fig. 3), wrote that:

> Seeing this vase prompted a long conversation about when a bowl becomes a vase. Fundamentally, the shapes are not that different. While trivial, I think this debate shows a larger aspect of museum organization in that the museum must make critical choices to distinguish objects that may not be that different.

The apothecary jar, ornamented with cherubs and now missing its lid, has few visual similarities to vessels we store our medicines in today, such that it appears more like a decorative vase to the student. The student's description of the object as a "vase" instead of "jar" reveals how categorization draws on one's own assumptions and often requires specialist knowledge. While the student discussed drawing lines between typologies of objects as "trivial," they actually pointed to a fundamentally difficult aspect of database design (and one that is frequently overlooked): the need to assign things to categories.

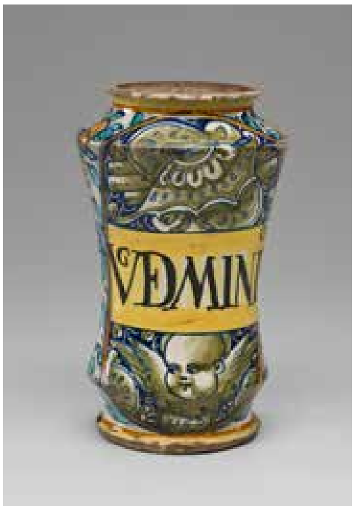

Fig. 3: *Maiolica Apothecary Jar with Floral Decoration and Medallion of a Cherub and Trophies*, Faenza, Italy, 1569. Pottery with cream-yellow glaze. Allen Memorial Art Museum, Oberlin College, Gift of Robert Lehman, 1944.40

In databases, records are assigned categories in order to make it easy to produce a list of records that fit a specific category. However, in real-world database development, programmers frequently encounter records that do not neatly fit into one category or the other; for this student, a "vase" and a "bowl."[2] Programmers must either make a judgment call on what category a record belongs in, ask a domain expert or database user what category it belongs in, or complicate the database schema by allowing records to have multiple categories. The miscategorization of an object based on an incomplete understanding of it can have impacts on the end user. Had the museum allowed this computer science student to categorize this object as a 'vase' or a 'bowl', or even as both, it would have been lost in the database to researchers with specialist knowledge searching for 'jars' or more specifically 'apothecary jars.' Yet the student's own conundrum reveals that the inverse is also true, in categorizing objects solely by specialist terms a wide range of people might not be able to understand an object's function or history.

Starting in 2005, one group of museum informatics researchers led by Susan Chun and Jennifer Trant at the Metropolitan Museum of Art responded to this challenge by working with visitors to produce 'folksonomies,' or taxonomies created by nonspecialists, by adding 'social tagging' that could introduce new search functionalities in their database. Their tests suggested that 90% of the terms general audience members used to describe artworks were not included in museum documentation (TRANT & BEARMAN 2007; TRANT 2009). The database tool, known as Steve Tagger, responded to the interactivity of Web 2.0 technologies and pushed against the standardization and controlled vocabularies for museum databases that had emerged in U.S. museums in the late 1960s, alongside the introduction of internal automation technologies, to allow for quicker retrieval of collections information (JONES GARMILL 1997, 35–37). In the decades since, multiple data standards, thesauri, and nomenclatures have been developed to meet the needs of different types of museum collections. The *Art and Architecture Thesaurus* (AAT), for example, was founded in the 1980s to build a "consistent, comprehensive, and controlled vocabulary that would be used by [museum] database developers, but that at the same time would not conflict with the working language of scholars and researchers who would be the users of the databases" (JONES GARMILL 1997, 43). AAT's mission reveals that the original museum databases were not conceived of as public facing, as they are now. It was not until the late 1990s that there was a push for institutions to make such information as publicly accessible as possible, including online (DONOVAN 1997; BURTON JONES 2012). Making museum objects and their histories accessible to a wide range of possible users hinges on these questions of terminology and the need to balance specialist knowledge and generalist interests. Museum

[2] For a recent example of this in social media, see BIVENS 2017 discussion of the evolution of gender categories on Facebook, and their implications.

databases, like physical museums, are meeting points for diverse perspectives and expectations that can make the seemingly trivial task of categorizing, describing, and naming a powerful one.

In our assignment, the group that was assigned the Title column, an open text field containing the object's title, grappled with the complexity of the seemingly simple task of giving an object a name. By looking at the column data they recognized that some pieces had specific names, such as *Imari-Style Ribbed Bowl with Interior Design of a Woman in a Garden*, while others were simply *Bowl*. They also discovered that "some bowls have very similar names, but different appearances." Several titles included the phrase "geometric" though the designs were visually different, thus indicating a generic term was being used to encapsulate a range of cultural approaches to decoration. Having to sort through this column and compare the contents of the data field to the physical object revealed to the students that the designers of the museum's database made a fundamental assumption that every object that would appear in the database would have a title. However, most objects do not have titles given to them by their maker, leading the museum professional tasked with naming them to resort to repetitive or simple descriptions.

Issues with names, both of objects and people, are common in database design. For example, the popular blogpost "Falsehoods Programmers Believe about Names" (MCKENZIE 2010) lists many false assumptions about people's names that are erroneously built into database systems, such as that "people's names do not change." Many of these suppositions about names have consequences for how well a person's name can be represented: longer names may be cut off if the field is too short, and assumptions about what typographical characters will be used can result in the erasure of accents or umlauts. This frequently has the unintended effect of making it impossible to properly represent names of people from cultures other than that of the database designer. A common example of this in the United States is that people from Spanish-speaking countries who have two last names cannot be properly represented in American databases that assume a single first, middle, and last name. In the AMAM database such assumptions about names impacted the findability of three works by the engraver whose name appears in the database as Diana (Ghisi) Scultori (1547–1612), but who is also known as Diana Ghisi, Diana Scultori, or Diana Mantovana for the city of her birth.

Intended User

Museum databases make vast amounts of information about expansive collections accessible to two primary types of users: internal museum staff and external visitors. Museum staff use it in their daily work to track and find information about objects or quickly export it into labels or reports. The same data fields are also repackaged and delivered to the general public through the museum's online database, often with the promise of making collections information more accessible to researchers and other visitors. The students' investigation of how well they thought a column represented the object and what information might be missing revealed that the needs of one type of database user might make some data more or less usable to another user.

Fig. 4: *Coiling Dragon*, Japan, late 19th century. Bronze. Allen Memorial Art Museum, Oberlin College, Gift of Charles F. Olney, 1904.723A-C

The group assigned to the Dimensions column, which consists primarily of overall measurements recording width *x* height *x* depth, began to see how the database designer's simplifying assumptions impacted the usability of this particular dataset. Responding to the prompt asking them to select a group of objects that told a story about their column, they selected ten pieces that they felt were not accurately represented by the dimension column. For example, they said a late 19th-century bronze sculpture of a coiling dragon (fig. 4) "has a curved shape with sharp edges which emphasize the strength and power of the dragon; this is hard to be described by the dimension column." The limitations of the dimension column were different for a mantelpiece that "is embedded in the wall and does not take any space of the open area." Here the students discovered that the way in which the data is represented creates assumptions (in this case, that most objects in the collection will be roughly rectangular or cubic), and thus cannot capture the complexity of shapes that break from those assumptions. This is a key tension in both database design and all digital representations: simplifying assumptions are necessary in order to concisely describe objects, but by the nature of those assumptions they will not be able to completely describe all objects. Viewing objects firsthand in the museum offered a unique opportunity to discover the tension between the physical reality of the object and its database description.

The Dimensions category also opened up questions about the potential users of this specific data. For visitors looking at this field on the museum's online database, it could provide a sense of the artwork's scale, which is lost in its translation to a standard-size database image. In the context of a museum gallery, such data can be felt in relation to one's body and perhaps is not very useful. Internally, curators planning exhibition layouts or registrars determining how much space is left in storage might find this field very helpful. The students' critical questioning of a seemingly simple column thus offered an opportunity to think about how the same piece of data has different utility based on the intended user.

When tasked with making suggestions about how the database might be improved, we found that students made their own assumptions about who uses the database, but they weren't always thinking about the same user. A student commenting on a glass bowl from 19^{th}-century China (fig. 5) proposed that the database would benefit from having notes for curators about how the object should be lit because he felt that this was often overlooked and that "lighting can dramatically change the experience of an object." In this case, the additional field would store practical information for the curator, which is more often kept in personal or paper curatorial files. Another student, discussing Paul-Albert Bartholome's *Girl Crouching (Grief)* (1885–98) thought that what was missing was a column including a physical description especially for visitors who are blind or have low vision. This imagines another purpose for the database: as a tool for making the museum more accessible for visitors with disabilities. Several students remarked that the database was missing key contextual information, such as the artistic movement, "the meaning of the work," or "the artist's cultural background vs. their cultural surroundings at the time of painting a piece." The students' suggestions that more contextual information or interpretation—such as is usually contained in an extended label or essay—was needed reveals that the discrete descriptive pieces of data did not allow them to understand the object as fully as they had wanted to.

Fig. 5: *Convoluted Flower-Shaped Peking Glass Bowl*, China, 19^{th} century. Glass. Allen Memorial Art Museum, Oberlin College, Gift of Judith Gerson in honor of John L. Young, 2008.34.13A

One student was even ready to throw away the database all together writing, "I do not think any column in a database could capture what one gets from looking at the artwork in person, thus no columns are missing from the database…The way the artwork is arranged creates a certain ambiance that cannot be expressed within the database." Yet in his rejection, this student drew attention to an important element of the in-gallery experience other students had not touched on, namely that the database has a way of erasing curatorial choices such as the ordering of objects and thematic labels intended to place them into a larger context. In the online database, visitors are reliant on keywords or faceted searches to narrow down and find meaning in a seemingly endless scroll of collections information, while in the museum gallery the curator has already done this work for them. This student's comment points to the vastly different experience of finding information and meaning in a physical museum space and an online database.

All of the students' suggestions about how the database could be improved mirror recurring questions in the museum field about the role and function of a collection database. What truly is it meant to do? Which user or users is it meant to serve? Is it a tool for efficiently retrieving information in support of internal museum functions or research and teaching? Should it integrate the narrative structures of an exhibition (BESSER 1997)? Can the information held in a database become meaningful knowledge for visitors without additional interpretative materials (PEACOCK, ELLIS, & DOOLAN 2004)? Can a database enable public users to craft alternative connections between objects (CAMERON & KENDERDINE 2010)? Do the data fields that have become standard in museum documentation reflect visitor needs and complex cultural understandings of objects (SRINIVASAN 2009) or simply reveal institutional record keeping processes (GREENE 2016)?

Data Upkeep

As students thought about the instances where they believed the database did not meaningfully describe the object, they frequently suggested improving it through adding more information. For example, a group focusing on the Object Name column (which classifies the object using predetermined terms from a menu, such as 'bowl,' 'sword,' or 'sculpture') wondered how many possible options there should be. They mused, "you could also group them by function or you could group them further by each bowl's meaning (like religious, food, etc.)." This comment opened up questions about how much description is helpful. Do objects need to be uniquely described or differentiated by their names? How many different categories or subgroupings of bowls would be useful? While computer science students tend to be in favor of always adding more categories and more data, this ignores the fact that someone eventually will have to enter all of that data (and make the categorization decisions, which may not be known or obvious). In database design, the desire to keep as much information as possible about an object is always in tension with the fact that a database is a living artifact, into which more information must constantly be entered as the museum collects new pieces.

This brought up another pedestrian, yet important issue of databases: that they have to constantly be updated. Long before the AMAM's database existed in its computerized form, important information was held in the card catalogue and some information was even written on the interior of the matted artwork, such as in Albrecht Dürer's *Adam and Eve* of 1504 (fig. 6). Over time, and through much manual labor, these paper files were transcribed and digitized. While much key information about an object can be found in the museum database, other bits of data were never transcribed and exist only in the curatorial file or the card catalogue, both of which even today are considered the 'original' data. Because the work of updating and transcribing a database is frequently not done by the initial database designer but by someone else after the database is created, this work may be largely invisible and not considered by the designer. However, the students encountered these challenges of data upkeep immediately in this assignment when they discovered an object in the gallery that was 'missing' from the database. Soon they realized that the label indicated it was a recent acquisition, leading one student to the conclusion that "the database needs to be updated with all the data that is listed!"

Conclusion and Future Work

As implemented, the assignment described here took place during a single class period in the museum followed by written responses completed outside of class. Yet the richness of student observations suggest that this activity can productively open up larger questions at the heart of computer science courses as well as the profession of database design that awaits students after college. While some students failed, initially, to recognize the significance of their insights, they actually touched on deep issues within database design: the complexity of categorization, the challenge of weighing the intended users' needs, and the struggle to balance the desire for more information with the labor involved with data upkeep. In future iterations of the course, the instructor plans to spend more time after the museum visit drawing out the themes discussed above and connecting them to bigger issues in database design. This could include the art museum curator or other museum staff providing insights on how they actually use the database and their experiences working with it.

This exercise could also be adapted for other computer science courses. For example, an interface design or human-computer interaction course could have students look first at the collection on the website and explore the database before they visit in order to have students think more critically about the relationship between the experience of an object on a website and in person. This semester a professor of statistics and data science at Oberlin has adapted portions of the assignment described in this paper for his Introduction to Data Science course. Over a series of museum visits and related labs, students came up with new categories for the database and created new data for a select number of objects based on their own observations. Students will then analyze and visualize all of the new student-generated data and compare it with the museum-made fields. Though their final projects are still in process, the professor could already see that dealing with this 'messy dataset' cemented key concepts about data structure for his students. As a site that translates complex physical objects into digital data, the art museum offers a wide variety of issues to explore for computer science students.

Fig. 6: Cataloguing information written inside of the mat for Albrecht Dürer, *Adam and Eve*, 1504. Engraving. Allen Memorial Art Museum, Oberlin College, Gift of the Max Kade Foundation, 1967.33. Photograph: Hannah Wirta Kinney

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Keywords

databases, STEM, computer science, inquiry-based learning

Arts Research Integration and Collaborative Learning

Joey Orr and Daniel Tapia Takaki

The Arts Research Integration program at the Spencer Museum of Art at the University of Kansas recently supported the interdisciplinary inquiry Collective Entanglements, involving collaborators from art, mathematics, and physics. Together, the collaborators made an artwork that used mathematical analytical tools to explore questions in physics and the composition of video installation. Through exhibition, public programming, teaching, and publishing, the research collaboration demonstrated new approaches to integrating art and science in the context of an academic art museum at a research university.

A Brief Introduction to Arts Research Integration

The Spencer Museum of Art at the University of Kansas (KU) launched its Arts Research Integration (ARI) program in 2016. As the Spencer is embedded in a research university, ARI ensures the museum is an active participant in the university's research ecology at the level of question and method formulation. ARI also makes the case that the complexity of today's global problems requires researchers from a broad array of fields and disciplines, and artists should be more consistently included among them. Although many people implicitly experience art as a way to know the world, artistic practice can be better understood as a research method when articulated as practice-led research. This is somewhat a reversal of more traditional scientific methods, which tend to begin with a question or theory that is then tested through carefully planned and controlled experiments. Practice-led research tends to lead with a process of making or engagement that then gives rise to questions and theories, fostering creative ideas and new questions. Artistic research describes a diverse field and can include innovations that contribute to the development of a particular artistic medium or contributions to knowledge domains beyond the arts.

In 2019, the Spencer Museum published the book *Inquiries*, which articulated the following four pivotal ideas that continue to inform ARI's work: academic art museum's are active participants in a university's research culture; rigorous inquiry respects a diversity of methods; academic and institutional formats are never neutral; and social justice and research methods must be thought together (ORR 2019, 140–41). Although the effort behind the museum's program may seem novel, this is due more to a scarcity of practice and articulation in a U.S. context rather than a lack of historical orientation in the field. In fact, it is consistent with a long line of institutional research and curatorial thinking. In his book *The Birth of the Museum*, sociologist Tony Bennett makes an important claim about the curator, stating:

> …it is imperative that the role of the curator be shifted away from that of the source of an expertise whose function is to organize a representation claiming the status of knowledge and towards that of the possessor of a technical competence whose function is to assist groups outside the museum to use its resources to make authored statements within it (1995, 103–4).

The goal of the curator is not only to foster spaces and encounters that produce and examine knowledges but also to use this competency to enable others to formulate their own questions using institutional resources and capacities. Bringing together related discourses has long been considered part of curatorial research and practice. In a 2009 *Artforum* article, Swedish curator Maria Lind describes her thinking on "the curatorial" calling it a "way of linking objects, images, processes, people, locations, histories, and discourses in physical space" (2009, 103). In 2015, curator Henk Slager describes "a need for a form of thought that concentrates on artistic knowledge production, but which is simultaneously capable of manifesting itself as research within an institutional environment" (2015, 83). Several years later, there is now a concern that the aesthetic treatment of knowledge simply replicates the bureaucratic processes of educational capital that artistic practices can be invested in challenging (OSBORNE & STEYERL 2021). Thinking about research in the context of artistic and curatorial practice is an established discourse, and ARI's work focuses specifically on the integration of art practices with other fields and methods of research.

Collective Entanglements

The foundation for the Collective Entanglements project had been established over the previous decade, as the Spencer built out programmatically what had historically been a culture of investment in research. KU professor and high energy physicist Daniel Tapia Takaki helped to establish connections with the European Council for Nuclear Research (CERN). In November 2014, the museum organized a roundtable discussion with international artists and scientists, including representatives from CERN, to discuss how their disciplines stimulated and inspired one another. In 2016, ARI was established through a grant from the Mellon Foundation and the program was subsequently endowed. By 2020, Joey Orr, Curator for Research at the Spencer, had brought together a collective to support the furthering of this inquiry, including Tapia Takaki, artist Janet Biggs, and mathematician Agnieszka Międlar.

In the physical sciences, entanglement refers to sets of data that cannot be described independently of one another. In a more general sense, it refers to a complicated relationship or complex situation. It can also be useful in describing the integration of art and research. The three collaborators presented a project that used the time-based media of video and performance to explore questions in particle and nuclear physics through novel mathematical techniques. In 2022, ARI presented *Collective Entanglements*, an exhibition run as an experiment. The exhibition included an immersive, multichannel, synchronized video installation (fig. 1) and interactive whiteboard drawings with data captured and contributed from collaborators and visitors to the exhibition (fig. 2). The design of the installation responded directly to the architecture of the auditorium in which it was housed: the 3,000 square foot Beren Center auditorium, located in Slawson Hall of KU's Earth, Energy and Environment Center. A six-screen configuration constructed around a central column invited viewers to move around the installation. The projected imagery and sound were produced from prompts given to collective member Biggs (video/performance artist). The prompts, like entanglement, were all key concepts extracted from the broader research. Video images of lunar and solar eclipses merged and entangled with images of detection devices at CERN, dancers moving as if in micro gravities, and the collapase of Antarctic glaciers.

Using algebraic computations of data, such as the singular value decomposition (SVD) which is often used in quantum mechanics, collective members Międlar (mathematician) and Tapia Takaki (physicist) reduced the set of video imagery and sound to lower-rank dimensions. These low-dimension versions were reincorporated back into the installation, creating a multidimensional projection. Inspired by SVD, the exhibition soundtrack was composed as three separate lower-dimension approximations or melodies, played on violin, viola, and cello, respectively, that combined in the exhibition space to construct a higher-dimension composition. In physics, although not always recognized in the standard textbooks of quantum mechanics, SVD can be used to explore quantum phenomena. In particular, SVD can represent collider data that have not been adequately captured by instrumentation. Enough instances of low-rank information can be collected to build a higher-rank representation, which is a technique known as quantum tomography (MARTENS, RALSTON, & TAPIA TAKAKI 2018, 5). This is useful for a variety of physics processes. Tapia Takaki is particularly interested in studying particles that do not collide inside the Large Hadron Collider (LHC), phenomena the CERN experiments were not designed to observe. These types of physics processes are called "ultraperipheral collisions," which are near misses of the collisions. In an attempt to identify a prior state that instrumentation has not been able to document, Tapia Takaki must first distinguish signals from background, and then attempt to assemble instances of low-rank signals in order to reconstruct a state prior to the phenomena captured by the LHC—"the initial state." This work features effects

Fig. 1: *Collective Entanglements* installation view. Photograph: Ryan Waggoner.

of quantum entanglement, and so video and performance, as time-based media, might be useful tools for thinking through the probability of sequences and their possible initial states. These types of collisions are induced by high-energy photons or light, revealing "high-resolution pictures" of the proton or nuclei structure. These pictures might provide information about new phenomena such as "gluon saturation" (ALICE Collaboration 2023, 17). Reciprocally, SVD is interesting for video production, specifically for its ability to manipulate the data matrices representing the medium's images and sound. The installation explored data's legibility in dance and musical composition, as well (HURSHMAN & ORR 2022, 537).

Below is a description of twenty seconds of one of the bays within the larger installation.

> The screen on the left consists of a moving image that is not resolved. There are blurry blocks of colors—mostly whites, neutrals, and charcoals—until the eye reaches the top quarter of the image, at which point the neutral colors become layered with cool blues, suggesting an abstract landscape. On the right is documentation of the dancer Dahsir Hausif. He drops his head back until his entire torso falls out of view, while the camera pans up his arms, finally centering his hands. At the same time, the landscape on the left has been zooming in and finally the image resolves to reveal a pan across a landscape in Antarctica. But at the moment of its resolution, Hausif's hands now begin to pixelate. As they circle in a gentle spiral gesture, his pivoting body moves back into the frame, blurring. The effect washes over him, only obscuring the details, until the image is resolved again, and the dancer is standing upright and looking forward.

As the viewer moves through all six videos that make up the installation, it becomes clear that the work is alternating through stages in which the image is sometimes resolved as a realistic, and perhaps narrative, representation and sometimes less resolved, at times to the point of abstract color. This is the result of using tools for mathematical analysis on the moving image, and so the code itself was also sampled in the composition. Since the medium of digital video is, after all, encoded data, it is perhaps the moments in which the data become apparent that might be considered realistic in terms of the medium, and the moments of figurative clarity that are a kind of illusion generated by the data. The data is so central to the composition that it impacts all of its formal and material aspects. The work suggests a new iteration of an old critical move in cinema studies: apparatus theory. In short, the moving image conveys particular ideologies by creating a realistic experience while hiding the apparatuses that are creating it, like the camera and editing techniques. In this case, the work uncovers another invisible element in the construction of the digital image: data itself.

The video installation embraces and makes explicit the fact of data as medium. In connecting the two experiences of apparently higher and lower resolutions, the representational aspects of video and the visually abstract aspects also produced by the data become linked. The glitch created around Hausif's body, for example, is justified to the other formal components of the composition; it is in sync with the movement, color, shape, composition, and sound. In the end, the disruption of the resolved image is not a glitch so much as a periodic revelation of the work's apparatus—its underlying support. Instead of concealing data, the viewer can invest in it through the artwork, which does not reinforce an ideology of neutrality. Affective, embodied, and other kinds of

Fig. 2: *Collective Entanglements* installation view. Photograph: Ryan Waggoner.

human investment in data become possible. Then different questions can be asked of it, and it can even begin to be understood within a fuller spectrum of human capacities.

Psychologist Silvan Tomkins, who made the radical case that affect was the central mechanism in cognition, stated:

> There is a real question whether anyone may fully grasp the nature of any object when that object has not been perceived, wished for, missed, and thought about in love and in hate, in excitement and in apathy. In distress and in joy (2008, 75).

According to Tomkins, you cannot know something without at least the minor affective investment of a little interest. Is it so strange, then, to think about loving, hating, or missing data? In a recent talk by Mariko Silver, president of the Henry Luce Foundation, she addressed the siloing of emotional investment (MUSON, SILVER, & WILLIAMS 2022). People are expected to be emotionally invested in sports, for example, but not in departments of engineering. Personal investment in a subject means greater potential for the desire to be in relation with it, even to change it. This is precisely why artistic practice and other embodied, phenomenological, and affective forms of knowledge production should be more explicitly aligned. Data influences everything we do all the time, but by revealing it as an apparatus, we can begin to grapple with both its unexplored potential in producing the moving image and its attendant ideologies.

The work, therefore, goes beyond simply applying quantum tomography, SVD, or tensor-train algorithms to video and music data. This research into initial states (physics) and video composition (art) meant to challenge the prevailing view that quantum physics is a physical theory that describes objective reality. It proposed instead that it is a pragmatic tool that reflects human interactions with nature. It also suggested that quantum physics is a field of study that expresses a human desire for simplicity, and that every feature of quantum physics, including entanglement, is a result of human conventions. This project expanded the use of quantum theory beyond physics, as it has proven to be a useful tool for describing various phenomena. Entanglement does not contradict the classical notions of the universe but rather reflects our choices and limitations in understanding quantum probability, a new branch of mathematics that was unknown or ignored by the early developers of quantum theory. This work explored the limitations of entanglement, a fascinating but not inviolable feature of quantum physics. Quantum mechanics was shaped by the mathematical, social, and philosophical factors of its time. The early pioneers of quantum mechanics had to use new tools such as probability theory and linear algebra, which were not well established at that time. No quantum postulate is sacred (Ralston 2018, 10–38). The ARI project illustrates these points, representing a new quantum program.

Pedagogy and Student Involvement

Such complex research both leverages and reexamines ideas and methods in mathematics, physics, and video art in ways that open an interdisciplinary space for pedagogy and student skill building. The Museum and participating academic departments supported a number of student research fellowships. Two graduate students working in the philosophy of science spent one academic year each thinking with the researchers within their own scholarly contexts. One graduate student began to articulate the actual practice of scientific method as an embodied epistemology in the context of performance studies. The other graduate student described the collaborators' methods in the context of interdisciplinary tool sharing, which resulted in his first coauthored, peer-reviewed publication.

Two undergraduate students also worked closely on this project. One of the students was a physics major, who is also a professional jazz musician, and the second student was a math major with a minor in dance. These students participated in project meetings and in the creative process of making the exhibition. They brought together both their art and science training, for the first time, around a single project. They provided ideas and suggestions and helped in processing and analyzing data. Along the way, they learned new mathematical techniques that are applied in quantum mechanics, in particular the use of quantum tomography.

Several of the research methodologies and ideas developed during the ARI project were implemented in an honors research seminar taught by Tapia Takaki as part of the University Honors program for first-year students in fall 2022: "Art x Science and the Quantum Renaissance," where the "x" indicates the point that both art and science are entangled. The seminar discussed how physics research directions have been formulated and shaped by various scientific ideas and historical, philosophical, and artistic movements. The seminar examined concepts such as symmetry, perspective, light, form, color, shape, fundamentals, aesthetics, space, time, and dynamics from both scientific and artistic viewpoints. Some emphasis was put on questions that emerged from quantum entanglement. The students developed group projects that were guided by Tapia Takaki, and Biggs participated in a couple of course sessions helping the students to develop their projects. As part of finding their research questions, they also visited the Spencer Museum of Art and interacted with artwork that related to prompts they had prepared prior to visiting the museum. This work was done together with Celka Straughn, Deputy Director and Director of Academic Programs at the Spencer. Also in fall 2022, Tapia Takaki taught the first graduate course on quantum mechanics. Late in the semester when the students learned about concepts such as density matrices, they visited the Spencer and were in conversation with both Orr and Straughn. Orr has also included some of this work in a hybrid methods graduate seminar cross-listed with anthropology, art history, museum studies, and visual art.

A Word about Outcomes

Although largely focused on process and expanded methodological approaches, there have been many concrete outcomes from the research so far. In 2020, the collaborators presented their work in progress for a live peer-review session with *Ground Works*, a compendium of arts-inclusive, collaborative research projects supported by the Alliance for the Arts in Research Universities (a2ru) based at the University of Michigan. The collaborators also submitted their project and working questions through a letter of interest to Snowmass, the Particle Physics Community Planning Exercise held by the American Physical Society of Particles and Fields. On Thursday, April 8, 2021, the collaboration's live-streamed performance, *Singular Value Decomposition*, was presented by the Cristin Tierney Gallery in New York at ONX Studio. Applying prompts from physics to see what might be learned through interdisciplinary tool sharing, a dancer and musician became particles inside a performative experiment. In 2022, the program Arts at CERN published an interview with the collaborators, and *Leonardo*, an MIT Press peer-reviewed journal, published the article, "How to Do Things with SVD: Mathematical Tool-Sharing from Physics to Performative Research," coauthored by 2020–21 ARI graduate research fellow Clint Hurshman (KU Philosophy) and Orr.

Fig. 3: KU student engaging the interactive whiteboard around the perimeter of the video and sound installation. Photograph: Ryan Waggoner. © Spencer Museum of Art, University of Kansas

Work made through the collaboration has been exhibited several times already, beginning with its debut at the University of Kansas in 2022. It was subsequently included in the exhibition *Journey to Places Known and Unknown*, at the Sarasota Art Museum in Florida. Video documentation of the performance *Singular Value Decomposition* was also included in the 2020–21 group exhibition, *in Memoriam: anni horribles* at Campus Biotech, Geneva, Switzerland, where the collaborators participated in a panel discussion. Mędlar and Tapia Takaki continue to research questions related to the application of onboard artificial intelligence or quantum algorithm devices for collider physics. Two research proposals to the Department of Energy and the National Science Foundation have been submitted. In addition, Orr and Tapia Takaki are seeking funding to support an interdisciplinary quantum center where ARI will be one of the core directions. Recently, Agnieszka Mędlar invited Janet Biggs for a site visit to Virginia Tech, and visits to CERN continue as well. The collective continues to move forward with their work, even beyond the initial significant investment in the Collective Entanglements project by the Spencer Museum of Art.

Fig. 4: Participants from across fields and communities at one of the final roundtable discussions. Photograph: Ryan Waggoner. © Spencer Museum of Art, University of Kansas

During the three days of public engagement around the exhibition at KU, formats were varied to support a wide spectrum of learning and to increase access to ideas that often seem opaque to general audiences. Lectures, panels, and exhibitions, often occurring within the space of the installation, were the main programmatic scaffolding, with presenters including physicists, mathematicians, artists, graduate students, and the public. The culminating roundtable discussion was completely open to the public, with no one person or subject dominating the inquiry. The interactive whiteboards in the space also created an opportunity for the comingling of institutional didactics, artist statements, and mathematical equations with drawings and commentary created by those who attended and participated in various ways. ARI provided a sense of community and belonging to participants, and it represents a model of community engagement within campus that has great value for both education and research, done through collaborations between scientists and artists.

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Teaching Geosciences with Museum Collections: Curiosity and Connection

Jennifer T. Cholnoky

Many students who take an introductory geosciences course in college enroll to fulfill some type of distributive requirement. These students may be apprehensive about taking a college-level science course and/or ambivalent about the relevance of the course to their interests and values. An on-campus field trip to the Frances Young Tang Teaching Museum and Art Gallery, at Skidmore College, provides an unexpected change of venue for students and encourages them to think of the geosciences as interdisciplinary and the associated content and skills as more broadly applicable than they expect. During the visit, students practice their observation and interpretation skills and explore the intersection of art and the geosciences across three broad themes—earth as media, earth as subject, and earth as backdrop or 'canvas' through a variety of activities, including slow looking, small-group discussions, and facilitated whole-class discussions. A post-visit creative project assignment invites students to explore these connections more deeply and individually, using the medium of their choice. This suite of activities engages students with the geosciences by leveraging curiosity and connections and by refreshing group dynamics in positive ways.

Introduction

At colleges and universities with distributive requirements for undergraduates, there will likely be a cohort of students who take an introductory science course out of obligation rather than for reasons of interest or future career goals. These students often arrive in the classroom apprehensive or anxious about taking a college-level science course, and they may also be ambivalent about the relevance of the course to their broader course of study and postcollegiate plans. Depending on the curriculum requirements, this course may be the only science course a student takes during their college career. Faculty who teach these courses are well aware of the variety of reasons students enroll. In addition, there is increasing awareness in the sciences around issues of inclusivity and belonging so faculty strive to create inclusive learning communities at the introductory-course level.

Leveraging individual curiosity can prime students to learn and encourage them to make connections and find relevance in the course curriculum. Doing so in a new or unexpected venue can heighten the experience and remind students that they have many resources at their disposal on their campus, ripe for the taking. In addition, a change of location or an unexpected topic can help students think more broadly about how their skills and experiences have value to the learning community.

Dedicating a class or lab block to an activity at the college art museum is an incredibly effective and rewarding way to accomplish these outcomes. It can pique curiosity, demonstrate the transferability of skills, change up class dynamics, and give students the opportunity to share their different areas of expertise. It will also serve to facilitate developing and reinforcing students' connections with the course content and other subjects, disciplines, and interests. Most importantly, a STEM-focused museum activity highlights the interdisciplinary nature of inquiry.

GE-101

Each semester I teach an introductory course, GE-101: Earth Systems Science, at Skidmore College, a small liberal arts institution in upstate New York. The course covers a variety of foundational geoscience topics like rocks and minerals, plate tectonics, water resources, and local geologic history. A number of the course outcomes are fundamental and eminently transferable to other disciplines or inquiry-based practices:

- Make observations of geologic materials and processes;
- Develop interpretations based on observations;
- Make connections with the geosciences and other topics or interests;
- Explain why the geosciences are important.

Many students come to GE-101 each semester with limited understanding of how the course will be relevant to their interests, major, or career goals beyond checking a needed box on their transcript. Leveraging curiosity and highlighting connection are effective ways to encourage student engagement and participation. Many of our modules begin and end with asking students to consider how this topic is important or relevant beyond the walls of the classroom.

One of the most successful activities in the course, if perhaps unexpected for some students, is an on-campus field trip to the Frances Young Tang Teaching Museum and Art Gallery on campus. Through a series of activities, students engage with objects from the collection and consider connections with GE-101 content and skills that they have been learning during the semester.

These exercises grew out of a personal interest in the intersection of geosciences topics and visual art. What began years ago as a short lecture created to engage the interest of many of the non-science students in the course has developed over time into one of the mainstays of the class. The museum exercises were developed in collaboration with colleagues at the Tang Museum. The Tang Museum supports curricular innovation at the college through a huge variety of workshops, consultations, and other programming throughout the year.

Looking at an art object and looking at a geologic feature, such as an outcrop, are very similar exercises (figs. 1–2). Viewers step close for a detailed look and then step back for a broader view. Observations are made, and questions come to mind. For students who are less familiar with object-based pedagogy, simple prompts can scaffold the exercise and encourage exploration. “I notice…,” “I wonder…,” and “It reminds me of…” are ways to encourage attention, curiosity, and making connections with other topics and experiences.

Fig. 1: Students study artwork the Tang Museum. © Tang Museum

Fig. 2: Students study an outcrop in Saratoga Springs. Photograph: Jennifer Cholnoky

Another effective technique is an inquiry-based teaching method called Visual Thinking Strategy (VTS). VTS was developed by cognitive psychologist Abigail Housen and museum educator Philip Yenawine (Visual Thinking Strategies 2023). During a VTS exercise, a facilitator asks viewers to look at an artwork and then share their observations and thoughts. Prompts are very simple and open: What’s going on here? To deepen students thinking and engagement, this can be followed up by: What do you see that makes you say that? What more can we find? With these simple prompts, students are encouraged to share their observations and their interpretations in a supportive environment. There are no wrong answers; however, students are encouraged to support their interpretations with explanations and observations.

Tang Museum Visit

A GE-101 field trip to the Tang Museum consists of a series of activities that build on each other to help students practice skills, consider the content they have learned thus far in a new context, and support an inclusive learning community. With the help of a museum colleague, we begin with a short VTS warmup, typically using an object from a current exhibition in one of the galleries. Parallel to an introductory science course, students arrive at the Tang Museum with varying degrees of comfort or confidence in the skills they feel they bring to a museum setting. Some may be ambivalent or wonder at the relevance of the field trip to their course.

A short opening VTS session gets students comfortable in the space and demonstrates that they can all contribute to a discussion about an art object. At the end of this activity, I ask them pointedly what this has to do with GE-101. Because the VTS approach is so fundamental, and because we have been working on making observations and interpretations in class, it usually does not take students much time to understand that skills they have been developing thus far in class are transferable and applicable to this activity.

For the rest of the visit, we move to an area that has several (six to eight) objects from the museum collection that have been identified specifically for the GE-101 students. I work with a museum colleague ahead of class to choose artworks and artifacts that have readily identifiable connections to topics and themes from the course. In addition, we try to choose pieces that represent a diversity of media, artists, and time periods.

The rest of the class visit includes short activities that progress from individual to small-group explorations, with a final component during which each group shares their findings with the rest of the class. The students start by taking a short tour of the objects available. I instruct them to settle in with one that elicits a reaction in some way—it can be interesting, pleasing, or discomforting to them. Once the students have chosen a piece, they are asked to complete an individual slow looking exercise. They are instructed to spend ten uninterrupted minutes writing about their object. The only stipulation is that they must spend the entire time writing. They can write whatever they want, but they must not stop. They are encouraged to return to the VTS and scientific-exploration prompts if they feel stuck at any point.

Next, students work in small groups (two to three students works best) to discuss an object. It is at this point that students are prompted to make more specific and explicit connections with geosciences topics and concepts from the course if they have not done so thus far. To scaffold their discussions, they are given three broad themes to consider. (Note: all of the artworks pictured in this article are part of the Tang Museum collection and have been used for these activities.)

Fig. 3: Keith Edmier, *Cycas revoluta bulbil*, 2003. Acrylic, cast urethane form on basalt base. Frances Young Tang Teaching Museum and Art Gallery, Skidmore College, Gift of Marianne Boesky, 2015.38.1. © Tang Museum

1. Earth as Medium

There are plenty of examples of how earth materials are used to create artistic works. Starting with the earliest artworks in prehistoric caves, made on limestone walls with ochre pigments, earth material has been a medium for a wide variety of artistic expression. Rocks are used for sculptures (fig. 3), minerals are ground to create paint pigments and ceramic glazes, graphite and clays are used for pencils, silver is used for daguerreotypes and black-and-white photography, and metals are melted or alloyed for sculpture and jewelry.

2. Earth as Subject

Landscape art is a familiar genre for most people, and many examples can be found across cultures and time periods. Features such as mountains, oceans, rivers, valleys, and plains have served as inspiration and subject for many artists through time (fig. 4).

Fig. 4: Diane Burko, *Grinnell North Moraine 1, 2 (Grinnell North Moraine, 1922, after Elrod Toole / Grinnell North Moraine, 2008, after Lisa McKeon)*, 2010. Diptych, oil on canvas. Frances Young Tang Teaching Museum and Art Gallery, Skidmore College, Gift of Michael I Basta, 2015.25a–b. © Tang Museum

3. Earth as Canvas

For some artwork, the choice of location is integral to the work itself. This is particularly evident in large earthworks with a long history ranging from neolithic structures like Stonehenge to contemporary works by the likes of Christo and Jeanne-Claude. These works are site specific, chosen for the importance that the location brings to the artwork. Smaller-scale artwork can also engage with this theme in meaningful and often interesting ways (fig. 5). For our final portion of the activity, each group reports out to the rest of the class on their object and gives a short recap including connections to coursework. This leads to particularly rich discussions—students bring their own knowledge, interests, and experiences to their conversations with their peers. They will make note of commonalities and points of difference that they found with each other. In addition, as the discussion progresses, there are opportunities for objects to be in conversation with each other as groups make comparisons or echo each other in their reports.

Fig. 5: Mark Klett, *Viewing Thomas Moran at the Source, Artist's Point, Yellowstone*, 2000. Gelatin silver print. Frances Young Tang Teaching Museum and Art Gallery, Skidmore College, The Jack Shear Collection of Photography, 2015.1.397. © Tang Museum

Assessment

Students are formatively assessed during the field trip through feedback and ongoing discussion with the instructor, museum educator, and their peers. In addition, students are asked to engage with the concepts and themes from the field trip further with an assignment to create their own artistic piece that engages with concepts from GE-101 and the intersection of geosciences and artistic expression. Students are given broad choice in their choice of project—they are not limited to creating art objects of the kind we saw in the museum. They may submit musical pieces, dance choreography, a piece of creative writing, fiber art, a dramatic performance, etc. They are not assessed on artistic skill but instead are required to submit an artist's statement to accompany their piece. They are prompted to explain their inspiration, methods, and specific connections with the geosciences that they explored in their piece.

A final component of the assignment asks students to view the work of their classmates (either in person or in an online exhibition) and write a short response and peer review of one or two pieces.

Discussion

The conversations that occur with students during a museum visit are opportunities to model the skills and methods you want them to develop. Adding commentary about how certain objects were chosen based on curiosity and connections can highlight for students that these skills are in constant play. In my experience, there are often times when students make observations that bring new information to the instructor or the museum faculty. For example, a few years ago, a sharp-eyed student noticed a crouching figure in the lower-left section of a documentary photograph of Perched Rock (fig. 6). Neither the museum curator co-facilitating the group nor I had never noticed the figure, despite having used the picture for this activity several previous times. This was a

Fig. 6: William H. Bell, *Perched Rock, Rocker Creek, Arizona*, 1872. Albumen silver print. Frances Young Tang Teaching Museum and Art Gallery, Skidmore College, The Jack Shear Collection of Photography, 2015.1.368. © Tang Museum

wonderful demonstration for the entire group that there is always something more to discover and we can all learn from each other.

A field trip to a college art museum is also an opportunity to demonstrate how one navigates being out of their area of expertise. Modeling for students how you approach questions or gaps in your own knowledge, for example by calling upon the expertise of a museum colleague, can foster a supportive community. It can also be an effective reminder for instructors of how our students might feel as they embark on a class that is out of their comfort zone. The visit can serve as a powerful example of how an interdisciplinary approach to looking and knowing can lead to rich and nuanced exploration.

If possible, take advantage of the opportunity to make a visit the college museum for your class time. A change of venue can energize students and create a new dynamic during class. For some students, it may be their first visit to the museum. Your field trip can serve as an introduction to a resource with which they are less familiar. In addition, moving from a lecture hall or a science teaching lab to a museum can change up student demeanors and interactions. An art history or studio art major who is usually reticent in class might feel more in their element and ready to share their expertise in the museum. Conversely, science-oriented students may feel less comfortable in a museum setting and benefit from understanding that point of view.

If a museum trip is not possible, there are certainly ways to modify this activity and still gain many of the benefits. Perhaps someone from your museum can bring some objects to the classroom. Alternatively, many museums have at least a portion of their collections in online databases that could be curated for a virtual field trip. If available time and/or support does not allow one to devote a full class module to this amount of exploration, the activities could be scaled down or some work could be shifted to time outside of class. A short introductory video or slide show that outlines themes with examples could be followed by a scaffolded assignment for students to do on their own or in small groups.

The assignment that serves as a capstone to the experience is an opportunity for students to consider components of the course that they want to explore further in creative ways. Giving them the option to express themselves through a wide variety of media and genres allows them to lean into their interests and skills. The artist statement component allows students to explain their processes and the connections they explored in their work, even if the final product was not as successful as they would have hoped. This assignment always yields an impressive and interesting array of submissions. The Skidmore Geosciences Department logo (fig. 7) was originally created for this assignment by a studio art major with an interest in graphic design.

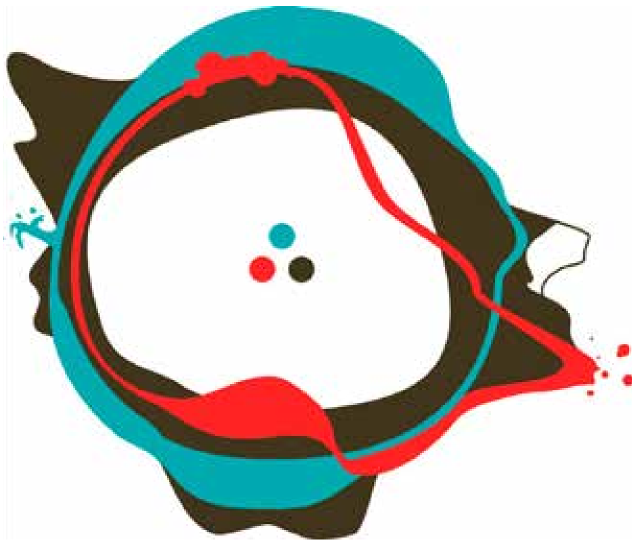

Fig. 7: Skidmore Geosciences logo, created by Alex Schechter, Class of 2014, for a GE-101 assignment. Photograph: Alex Schechter

As a final component, asking students to tour and reflect upon their classmates' work through an exhibition (whether online or in person) creates space for them to learn more about each other. It allows them to appreciate the wide variety of viewpoints, ideas, and skills of their peers and fosters a supportive and inclusive learning community.

Conclusion

Taking time in an introductory geosciences course to visit a college art museum can benefit students and faculty in many ways. Through this interdisciplinary approach, students can appreciate the transferability of fundamental observational skills and develop their interpretive skills and application of knowledge in a novel environment. Students who are ambivalent about the applicability of a college science course to their own interests or career goals can explore course topics in ways that may be unexpected and help them find relevance. Science anxious students may find themselves in a more familiar venue that allows them to share their knowledge with their peers and faculty. Additionally, faculty can learn from their museum colleagues about art education as well as the materials and provenance of objects in the museum collection. These activities can also help faculty extend their relationships with their students as they learn more about the interests and backgrounds through various activities. The rewards that follow from a museum field trip by an introductory science course can be reaped for the rest of the semester.

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The Power of Thinking with Art: Expanding Ideas of Time and Space

Meg Urry and Sydney Skelton Simon

Meg Urry, the Israel Munson Professor of Physics and Astronomy at Yale University and Director of the Yale Center for Astronomy and Astrophysics, teaches an introductory physics seminar for first-year students that incorporates a visit to the Yale University Art Gallery that is facilitated and coordinated by Sydney Skelton Simon, the Bradley Associate Curator of Academic Affairs. Written as a back-and-forth from each of their perspectives, this paper describes Urry and Simon's collaboration in detail, offering a model for productively incorporating an art museum visit into an introductory science course to advance core curricular aims and boost student confidence.

MEG URRY Since fall 2019, I have been teaching the first-year seminar Expanding Ideas of Time and Space: Relativity, Cosmology, and the Universe. Open to students of all academic backgrounds, the seminar introduces fundamental ideas about the universe in which we live. Course topics include the nature of time and light, special relativity, general relativity, dark matter and visible matter, the big bang and inflation, black holes, galaxies, and the accelerating universe and dark energy.

Because students in the course are new to the college experience, I have a few goals beyond teaching them physics. I want them to express their ideas freely, to value their own perspectives and those of others, and to try to think deeply about time and space. I want them to understand how science works—how we test our ideas and reject those that don't work, how research is done, how education is funded, how investment in science advances humanity, and how we can never prove a theory is true. Finally, I want students to connect with one another, to feel welcome in class, to overcome their imposter syndrome, and to enjoy learning about the universe.

We start with simple ideas about time, and then I blow their minds with Einstein's Special Theory of Relativity. Einstein first reasoned that the speed of light (in a vacuum) must be constant for all observers, then showed how this leads to very weird effects that we don't notice in daily life because we never move anywhere near the speed of light. Specifically, two people moving at different (high) speeds will not agree on when something happens or how much time has passed. What we take for granted in daily life, Einstein showed is not the case: time is not absolute, and space and time are intimately connected.

I have the class do some simple relativity problems, with the mathematics employed in standard physics courses. To connect the physics back to the power of thinking, we talk about time during a class session at the Yale University Art Gallery. The students don't really know what to expect when I tell them we're visiting the Gallery. Nor did I when I first met with their educational staff.

SYDNEY SKELTON SIMON The Yale University Art Gallery, where I oversee university curricular engagement with the collection, hosts hundreds of courses from Yale and other colleges and universities every year. While many courses engage in a deep and sustained way, and several art history courses are taught almost entirely at the Gallery, faculty from a wide range of disciplines incorporate a single gallery visit into their syllabi as an opportunity for students to think in new and creative ways about their core course content. The embeddedness of the Gallery in the academic community is thanks, in part, to a recognition that museum educators and faculty alike can teach *with* art and not just *about* art. In addition to drawing out subject-matter connections with the Gallery's global collections, class visits can be used to develop critical skills and thinking dispositions, including visual analysis, constructing an argument, empathy, clear communication, and more.

In spring 2019, I collaborated with Ágnes Mócsy, 2018–19 Yale Presidential Visiting Fellow and Visiting Professor of Physics in Yale's Wright Laboratory, on her first-year seminar Physics Meets the Arts. As I described in an article for the *Yale University Art Gallery Magazine*, Mócsy's course introduced fundamental physics concepts to students through deep engagement with the arts (SIMON 2019). The class visited the Gallery five times over the course of the semester. For their final projects, students made a work of art inspired by a physics concept they had learned in class. These projects were presented in a classroom at the Gallery, and members of the Yale community and the broader public were invited to see them.

The course was exceptional in many ways, not least of which was that it was taught by a theoretical physicist/documentary filmmaker with a deep interest in, and knowledge of, visual art (THOMAS 2019). But elements of what it achieved could be accessed through more limited incorporation of engagement with art. Mócsy wants to make physics feel accessible to students of more diverse background than have traditionally pursued the major, and she saw engagement with works of art as potentially leveling the playing field. Looking at works of art together, the students developed their observational skills and were able to apply the physics concepts they were learning to something tangible and concrete. In other words, it is not necessary to design a whole course around the connections between physics and art to teach productively and effectively with works of art.

Fig. 1: Faculty from the Yale Department of Physics on a guided tour of the Yale University Art Gallery with Sydney Skelton Simon and Ágnes Mócsy, August 2019. Photograph: Yale Wright Laboratory/Victoria Misenti

Hoping to build on the success of this curricular collaboration, Mócsy and I led a tour for physics faculty in August 2019 to generate opportunities to connect the Gallery's collections in other physics courses (fig. 1). With faculty in the role of students, Mócsy and I visited four objects, leading the group in the same format as we had students in her first-year seminar. We always began with careful observation and description of the works of art, and then moved to drawing out potential connections to physics.

MU I participated in that tour and recognized the potential to incorporate a Gallery visit into my first-year seminar. In particular, the tour brought ideas about physics so readily to mind that I knew students would benefit from a similar experience. I contacted Sydney about setting up a visit early in the semester when the class would be discussing the concept of time, explaining that I was less interested in getting across any specific ideas about time and more interested in getting the students thinking critically, talking, and interacting with each other. In advance of the session, students were assigned a series of short articles from *Scientific American* that explore diverse aspects of time: how it is perceived, how it is measured, what it means, how it drives society, and so on.

We met in advance of the course visit and Sydney walked through several options of objects on view in the galleries related to time. Together we chose four works, in a range of media and from different collection areas, for the class discussion, establishing the structure we've employed for this class visit every year. In that first iteration, as in every year since, Sydney guided students in looking closely and discussing what they see in four objects. There are a few goals for the visit: to get students thinking expansively and creatively about time; to work on their observation skills, getting into the habit of looking and describing before jumping to analysis and interpretation; to get students in this first-year seminar to exchange ideas in an intellectual discussion and thereby build a sense of community and comraderie; and finally to introduce students to this amazing campus museum. For students who regularly frequent museums, the visit builds on their strengths, while for others, the visit gets them thinking in a totally new way.

SSS We've now hosted this course at the Gallery five years in a row, including one virtual visit, facilitated on Zoom, in September 2020. Since September 2021, we have divided the class of eighteen students into two smaller groups, each guided by a Gallery facilitator (me and the Lewis B. and Dorothy Cullman–Joan Whitney Payson Postdoctoral Fellow in Academic Affairs and Outreach). Both groups see the same four objects, but in a different order, which inevitably produces exciting variations in the conversations had at each work. We begin the visit in the Gallery's lobby, where we welcome students and review the Gallery rules. We clearly articulate the aims of the visit to the students, and invite them all to introduce themselves, and answer a fun ice-breaker question, to bring their voices into the space and affirm the value of their individual perspectives. Elsewhere, I have written about the critical importance of the greeting students receive for cross-disciplinary learning in the museum (SIMON 2024).

Every year, Meg works with me and the Cullman-Payson Fellow in Academic Affairs and Outreach (Danielle Raad in 2021 and 2022, and Miriam Stanton in 2023) to revise the itinerary for the visit. Small changes are made in response to what is on view and available to teach with each September, as well as reflections from previous sessions on what seemed to resonate most with students. This specific course visit has become a touchstone training opportunity for the Cullman-Payson Fellows because it occurs early in the academic year, the structure is well established, and the theme of temporality offers ample opportunities to explore new objects and connections between works.

We select objects that could be the basis for a rich discussion about multiple dimensions of time. Because we are a global museum, we are able to select objects from a range of cultures, time periods, and media. Objects over the years have included: painted cloud studies by the British artist John Constable; an Aztec calendar stone; a Japanese Kimono embroidered with flora of different seasons; an intricately woven basket by a once-known Pomo artist; a photorealistic still-life painting by contemporary American artist Audrey Flack;[1] and more. Using such a variety of objects within each session encourages students to think expansively and creatively about the topic, while also exposing them to a variety of collection areas, cultural contexts, and media.

Fig. 2: François-Marius Granet, *Interior of a Capuchin Convent*, ca. 1825. Oil on canvas. Yale University Art Gallery, Marion M. Kemp Fund in memory of her brother, Arthur T. Kemp, B.S. 1894, 1967.31

At each object, we enact a similar routine that begins with an invitation to look carefully. We introduce an activity designed to jumpstart

[1] Danielle Raad, the 2021–23 Lewis B. and Dorothy Cullman–Joan Whitney Payson Fellow in Academic Affairs and Outreach, and contributor to this journal issue, recorded an E-Gallery Talk about the painting *Time to Save* by Audrey Flack, noting its connection to the course Expanding Ideas of Time and Space. The video, produced by the Yale University Art Gallery in 2022, is available on YouTube: https://youtu.be/H-rPG1g1hEU?si=qquKIGxQgr7kXIVw.

close looking; this might be asking them to write a list of observations or to come up with a one-word description. In all cases, the students must spend time observing carefully before moving into an analysis or interpretation of what they see. As they share their observations with each other, students inevitably notice new things, deepening their visual understanding of the work. They also recognize the diversity of their individual perspectives due to a range of factors, including their physical points of view relative to the object and the background knowledge, experiences, and expectations they each bring to the Gallery. The educator introduces factual information about the work to help guide the conversation forward, with the aim of getting students to talk about how the work relates to dimensions of time and temporality. They are asked not only to think *about* the works of art but also to think *with* the works of art.

Fig. 3: Danielle Raad leading students in the course Expanding Ideas of Time and Space in a discussion with Kazimir Malevich's *The Knife Grinder or Principle of Glittering*, 1912–13. Oil on canvas. Yale University Art Gallery, Gift of Collection Société Anonyme, 1941.553. Photograph: Jessica Smolinski

One work we have used a couple times is François-Marius Granet's *Interior of a Capuchin Convent* (ca. 1825), a large painting by a French artist working in Rome that hangs in the Gallery's European galleries (fig. 2). It depicts the interior of a Capuchin convent during Mass. With just a bit of framing information, students were invited to make note of everywhere they saw time in this painting. The prompt generated a wonderful range of responses, from observations about the sense of an instantaneous moment captured, to clues about time of day and weather, to cycles of ritual, to the narratives depicted in the paintings and sculpture in the convent, and even the ages of the monks. The painting is accessible and quite large, and the prompt asks them to think about the myriad ways in which we all experience and measure time.

MU Another example is *The Knife Grinder or Principle of Glittering*, a painting from 1912–13 by Kazimir Malevich. It is a picture of time deconstructed. At first glance, the painting can appear abstract, but students quickly detect multiple representations of a hand or the knife, thus grasping that motion is being represented in a painting. Then they go beyond the issue of time, talking about the plight of the worker in a boring job, or the room he's in (where does that staircase lead?), and they talk among themselves (where exactly is the knife grinder's head?) (fig. 3).

I thought the Japanese silk kimono was an unusual choice.[2] It was very beautiful, and the design seemed (to me) subtle—but the students got into it right away. They were first asked to make a list of words or phrases in their notebooks to describe what they saw. After a few moments of individual looking and writing, they shared their observations with the larger group. While some of their words and phrases were purely descriptive, others tapped into the emotional and poetic resonances of the garment. They talked about different seasons being represented by different flora at the top and bottom, and then identified a stylized river as the flow of time. Some students were prompted by the imagery on the kimono to think about how they experience the passage of time in their own lives.

Some of this successful discussion is due to the imagination of the students, and their openness of expression, which might in part be because they are new to college and have not yet learned to hide

[2] *Short-Sleeved Kimono* with Landscape, Japan, 19th-century. Satin damask (rinzu), resist dyed and embroidered. Yale University Art Gallery, Hobart and Edward Small Moore Memorial Collection, Gift of Mrs. William H. Moore, 1937.5889

themselves. But a large part of it is the skill and patience with which the educational staff ask questions and respond to input. Like the best teachers, they outwait awkward pauses and make sure all students are heard.

Our visit to the museum touches something in these students that science classes do not usually reach. Their own subjectivity is foregrounded. They analyze without resorting to an explanatory text. There is no right answer, just interesting observations that may or may not be echoed by classmates. The museum visit appeals to those for whom physics equations might be a turnoff. It enforces the idea that everyone is welcome in a science class and has valuable ideas to offer. Although I emphasize this with the students from the beginning, I know the museum visit helps the more art-oriented students believe they belong.

Beyond the four works we discuss in the session, Gallery educators also generate a longer list of objects that relate to time in evocative and varied ways. I encourage students to return to the museum and to bring a friend, incentivized by bonus points if they submit selfies taken in front each of the objects on the long list. After the visit, students are asked to write a short essay about how one of the pieces inspired them to think about time and space. These assignments encourage them not only to think about time in deep ways but also to walk around the museum, without a guide, and to think about art on their own—all while talking among themselves and building community. Maybe it helps them feel at home in the museum, or perhaps to make a new friend. Whatever their motivation, the return visit helps reinforce the experience and connect it back to what they are learning in class.

SSS For the majority of students in this first-year seminar, their class visit is the first time they set foot in the Gallery. For some, it is the first time they have ever visited an art gallery with a sense of purpose. In addition to giving them the confidence to contribute to their seminar discussions and to find their voice in the discipline of physics, we also aspire to instill in all the students a sense of belonging in the museum. In the galleries, they see in Professor Urry a scientist taking an interest in what can be learned through engagement with works of art. And they see in the museum educator facilitating their visit someone open to their perspectives and learning alongside them as they unpack a sequence of artworks.

The structures of the class visit and of the follow-up assignments are designed to give students tools with which to approach new-to-them works of art, to ask questions, to make connections, and to wonder. Of course, these skills extend far beyond the walls of the museum, helping to cultivate their curiosity about the world and build critical thinking skills.

MU Physics underlies everything—it is the foundation on which other sciences are built—and the tools of physics are used to analyze situations across many fields. Most people do not become physicists, of course, but I believe everyone will benefit from understanding some basic concepts. In the best case, it will make them see the world differently. Certainly, Einstein's Special Theory of Relativity, published in 1905, and his General Theory of Relativity, published a decade later, upended conventional notions of time and space. At a minimum, physics students will grasp the enormity of what they, and we, do not yet know.

It is also true that the challenges our world faces are often technical in nature, requiring scientific knowledge or approaches to solve. Again, not everyone will engage directly in solving such problems—but as participants in our society, as taxpayers, as (possibly) leaders in other arenas, they should understand the process of science and how scientists work.

These are the two loftiest questions my seminar tries to address: what is the physics of the universe, and how does science work? The canvas doesn't get larger than that. Without a doubt, the museum visit a few weeks into the semester instantly broadens students' horizons, helping them think beyond their initial expectations of a science class. They dig inward and think outward. This is what I hope for and see.

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Interweaving Themes in Physics and Art: A STEM-Museum Collaboration

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Physics and art represent the world in seemingly different ways, yet they share many common themes. Close observation of artwork by contemporary artists, as well as cultural artifacts from around the world, can guide introductory physics students toward an intuitive understanding of some of the most exciting concepts in physics. This article examines pedagogical modes used throughout the course Interweaving Themes in Physics and Art and how this approach provides pathways into the physics major for students from diverse backgrounds and different levels of preparation.

Introduction

At first, physics and the visual arts might seem to be as far apart as two academic disciplines can be, given their disparate subject matter, goals, and modes of reasoning. Indeed, art typically revolves around the human experience, while physics abstracts away individual perspectives to better get at the universal behavior of matter, energy, time, and space. However, overlap between the two not only exists but turns out to offer a rich arena for developing novel pedagogical approaches to teaching physics. The present article explores the possibilities inherent in this academic intersection through a collaboration between the Mount Holyoke College Art Museum (MHCAM) and the Mount Holyoke College Department of Physics. In particular we convey the lessons learned from teaching a first-year seminar—Interweaving Themes in Physics and Art—which features engagement with MHCAM as a central component. We believe that these lessons will be useful for both STEM instructors looking for a novel way to engage with their students and museum staff looking to widen their art and material culture teaching collaborations across subject areas.

Museum Collaboration with STEM Disciplines

MHCAM has a long history of collaborating with a range of academic departments, having formally launched its Teaching with Art program in 2009 with a grant from the Mellon Foundation. Since then, MHCAM has developed close collaborations with faculty in multiple STEM disciplines, including biology, neuroscience, chemistry, and mathematics. One of the oldest of these collaborations is with the Department of Biological Sciences. In partnership with the Yale Center for British Art, MHCAM adapted their long-standing "Enhancing Observational Skills" program designed for first-year medical students, to dovetail with the learning goals of Mount Holyoke's undergraduate curriculum in introductory biology courses.[1] Every fall, most entry-level biology students visit the museum to practice their observation skills while simultaneously learning about how to identify unconscious bias and assumptions they may make from prior knowledge.

Similarly, other collaborations with STEM classes have focused on skill building during visits to the art museum. Examples include using artworks as objects for scientific analysis, such as utilizing infrared and ultraviolet light in a chemistry class to see through surface layers of paintings demonstrating the properties of visible and invisible light, or a mathematics class studying perspectival drawing techniques in prints, drawings, and paintings.

One recent innovation, based on the collaboration with the course Interweaving Themes in Physics and Art, goes beyond skill building and intentionally engages students with the subject matter of specific artworks. The goal of this interaction is to inform and develop students' intuitive understanding of physical phenomena. During each visit, students—both individually and collectively—carefully study the content and visual properties of artworks. With guidance from their professor, the students have discovered new layers of meaning within the art, enabling museum staff to deepen their understanding of works in MHCAM's collection. There have been thrilling moments, for example when a student was able to explain to a curator or educator contextual information relevant to decoding a work of art or to reveal an artist's intentional creation of detailed patterns—such as in works by Anni Albers or Mel Bochner—that may

[1] For a more detailed overview of this collaboration, please see Linda Friedlaender and Ellen Alvord, "Visual Literacy and the Art of Scientific Inquiry: A Case Study for Institutional and Cross-Disciplinary Collaboration," in *A Handbook for Academic Museums: Exhibitions and Education*, ed. by Stephanie S. Jandl and Mark S. Gold (Boston: MuseumsEtc, 2012), 144–65.

have otherwise remained elusive to someone familiar with art history but not the foundational concepts of physics. This reciprocity has made the collaboration between the Department of Physics and the art museum particularly rewarding.

The Intersectional Space of Physics and Art

At a fundamental and perhaps surface level, physics and art intersect because many artists work with physical materials and with specific material properties. As a starting point, this recognition leads to a rich history of artistic innovation. From optical aids like the camera obscura, to the development of synthetic pigments, and on to more modern inventions like neon lighting, artists have consistently been early adopters of physics-based inventions. Furthermore, creating representational art requires that artists become keen observers of the physical phenomena around them. By endeavoring to capture the essence of fluid flow before the advent of cameras, generations of landscape artists observed the fact that turbulent fluid flows consisted of vortices of many different sizes. This observation was only realized in the physics literature in the early 20th century. For some artists, physics is also a source of inspiration or a way of grappling with difficult ideas. For instance, William Kentridge, through his multimedia work *Refusal of Time*, wrestles with the notion of entropy, the 'arrow' of time, and the fate of information in black holes.

In addition to these somewhat straightforward connections, art provides an accessible realm in which students can explore more abstract themes common to both physics and art such as the guiding role of symmetry, the tension between order and disorder, the emergence of structure from many simple constituents, and the role of aesthetics. While a deep understanding of the physical ideas reflected in these themes usually requires many years of math and physics courses, students can quickly develop intuition for these concepts by actively engaging with works of art that deal with them. Using close looking, small-group discussions, drawing, label writing, and curating a virtual exhibition, students in Interweaving Themes in Physics and Art build up analogies that can leverage their understanding of these themes in art to gain an appreciation of some of the big ideas in physics, including quantum mechanics, relativity, entropy, and chaos theory. Crucially, most students have immediate opinions about art (in general, or more commonly, opinions about any given specific work of art). This considerably lowers the bar for starting discussions, and invites a much wider group of students to consider the beautiful ideas inherent in physics.[2]

Engagement with a diverse group of students is a main motivating factor for this course. Unfortunately there is a persistent representation problem in physics. Despite making up 58% of the college age population, women receive only 25% of the physics bachelor's degrees as of 2021 (statistics per the American Physical Society, or APS, and the Integrated Postsecondary Education Data System, or IPEDS). Similarly, only 3–4% of bachelor's degrees in physics are earned by Black and African American students, while this demographic comprises 15% of the college-age population (IPEDS, U.S. Census, and APS 2020). Hispanic and Latino students, who make up 23% of the college-age population, obtain 15% of physics undergraduate degrees (IPEDS, U.S. Census, and APS 2020). While similar demographic data is hard to come by for self-identifying LGBTQ+ students, there have been climate reports (APS 2016), detailing how LGBTQ+ physicists often feel the need to hide their identity. These numbers speak to underlying systemic issues with how physics is taught and certain aspects of the culture surrounding the discipline. Aside from the moral issue of excluding, effectively, a portion of the population from being successful in physics, physics itself is deprived of the heterogeneous ideas and perspectives that result from diverse representation.

Fortunately, many members of the physics community are putting in the work to identify these systemic issues and develop solutions. Over the last twenty-five years, physics education research (PER)—the study and development of best pedagogical practices in physics—has grown significantly. The 'sage on the stage"'model of lecturing is being replaced (often at the rate of faculty retirement) with active learning models. Crucially, these modes of teaching measurably increase student learning and boost student retention within physics. While these efforts boost retention in introductory physics classes and arguably set the stage for a more welcoming environment in physics departments, they do not directly address

[2] Physicists often describe certain physical theories as being 'beautiful.' See the following article by Nobel prize winner Subrahmanyan Chandrasekhar: S. Chandrasekhar; Beauty and the quest for beauty in science. *Physics Today* December 1, 2010; 63 (12): 57–62. The actual correspondence between this and notions of aesthetic beauty in art are an interesting topic of debate, as is the utility of aesthetic judgments in the sciences.

the students who do not consider a physics major. In the leaky pipeline analogy, we have made progress on reducing the leaks, but still need a wider variety of students entering the pipeline. It is here that general education courses and first-year seminars can make a difference. Not only making the interesting, fundamental ideas in physics accessible but also demonstrating that physics is not walled off from the humanities can go a long way toward convincing a diverse group of students that their identity and interests are compatible with physics.

Origins of Collaboration

As is often the case, the path leading to this physics class partnership with the art museum came about circuitously, with initial connections forged during an interdisciplinary faculty seminar and then deepened through an exhibition collaboration focusing on a selection of science photographs by American artist Berenice Abbott. In January 2017, Associate Professor Spencer Smith, then a new assistant professor, signed on to participate in a multidisciplinary "Teaching with the Original" seminar hosted jointly by MHCAM and Archives and Special Collections (ASC). The goal of this seminar was to convene an interdisciplinary group of faculty to adventurously explore the benefits and possibilities of teaching with original objects and documents at Mount Holyoke College. Over the course of three semesters, a total of ten faculty members participated, representing a range of disciplines from anthropology to Africana studies and music to physics. During their sessions, faculty engaged in hands-on explorations of original materials together. The seminar format provided a useful gathering place for faculty to discuss and develop successful approaches to teaching with original art and artifacts and also to experiment with new classroom techniques by workshopping experiential learning sessions with one another.

As a result of working with Professor Smith in the faculty seminar, museum staff invited him to curate an exhibition in fall 2017 featuring a portfolio of twelve science-inspired photographs by Berenice Abbott. An opening in the museum's schedule made this exciting opportunity possible, and also enabled Professor Smith to explore an area of the museum's collection that would prove foundational for the new course he was designing. Abbott's black-and-white photographs are not only visually stunning, but they were used to illustrate the most influential physics textbooks of the 1950s and 1960s, and so were tied to the evolution of physics education in the United States. Adding to the exhibition's spirit of experimentation and collaboration, MHCAM hosted a label-writing workshop for the Society of Physics Students (SPS). With guidance from museum staff on label writing best practices and Professor Smith on scientific analysis, the students wrote brief and engaging artwork labels, making Abbott's photographs more accessible to the general public. [3]

Both the seminar and the exhibition enabled a deeper exploration of the subject matter and discussion of pedagogical ideas, as well as forged good working relationships, setting the stage for the first iteration of Professor Smith's Interweaving Themes in Physics and Art course in spring 2018. The course was then subsequently offered as a first-year seminar in fall 2021 and fall 2023, adapting it to specifically attract new students to explore the realm of physics in an accessible and engaging format. What follows is an overview of the structure and learning methodologies of the course as well as an in-depth examination of select themes and student reflections.

Course Themes

The course Interweaving Themes in Physics and Art is roughly structured around ten themes or concepts: symmetry, time, space, reductionism and emergence, fluid flow, quantum, color, chaos, minimization, and aesthetics. During each museum visit students interact with a curated selection of objects centering on one or more of the course themes. The pedagogical features common to every visit include small group work guided by close-looking discussion questions which allow each student the time and space to form

[3] For a helpful label-writing resource outlining how to craft engaging, accessible, visitor-centered exhibition texts, see The Smithsonian Institution's Guide to Interpretive Writing for Exhibitions. https://exhibits.si.edu/wp-content/uploads/2021/09/SI-Guide-to-Interpretive-Writing-for-Exhibitions.pdf (accessed January 17, 2024) For additional information about the exhibition Beautiful Physics: Photographs by Berenice Abbott, see https://artmuseum.mtholyoke.edu/exhibition/beautiful-physics (accessed January 17, 2024); to access the student-written labels, see the exhibition guide https://artmuseum.mtholyoke.edu/sites/default/files/beautiful_physics_labels_printPDF_w_logo.pdf?bc=node/1689 (accessed January 17, 2024)

their own thoughts; regrouping and reporting out as a whole class to share interesting ideas generated in small groups; and finally a short writing assignment to help students synthesize ideas and reflect on the physics theme. However, when it comes to how students interact with the art, a wide variety of pedagogical modes are used, including a scavenger hunt, close looking, drawing/tracing, hiding/revealing sections of an artwork, interactive viewing, comparing and contrasting object pairs, hypothesis building, label writing, and curating a virtual exhibition.

Here we take a closer look at four of the physics themes and the associated pedagogical modes chosen to engage students in the art museum. Throughout, student quotes drawn from their written responses to each museum visit highlight features of their interaction with art from MHCAM.

1. **Symmetries: Scavenger Hunt**

Symmetries are the mathematical description of patterns and therefore play an outsized role in physics, whose main goal is finding patterns in the behavior of matter. For instance, discrete symmetries lead to the classification of crystals—bulk matter formed from the periodic arrangements of atoms, while continuous symmetries are linked with conserved quantities, like energy and momentum, through Noether's theorem. Students can readily identify mirror symmetry, but often have a hard time coming up with more complex examples of symmetries or distilling many such examples down to a general definition of symmetry. The goal of our first visit to the museum is for students to gain familiarity with concrete examples of symmetry by interrogating art and material culture objects through this specific lens. Many students found this focus to be helpful:

> I've never walked through an art museum with a specific idea and purpose in mind before, so I was surprised how much it affected my experience during the small tour of our Art Museum. Usually I just walk through museums, stopping only to read the plaques and look at the pieces, but only at surface level. This time I kept symmetry at the forefront of my mind and it forced me to spend more time analyzing each artwork. Turns out symmetry pops up more in art than I originally thought.[4]

During this initial visit to MHCAM, we introduced students to the different galleries using a scavenger hunt. Each small group of students was given a card depicting the details of two artworks, tasked with finding both objects, and prompted to identify the types of symmetries present in each work. This was often not straightforward for the students:

> The symmetry in the artworks was not as obvious as we are used to having [from class discussion], but that made the scavenger hunt more compelling. Being paired in small groups provided me with the opportunity to discover the variations of symmetry in a new light.

Students noted that symmetry could be found in many aspects of a given object—its shape, painted or incised features, as well as certain subsets of these features. Often a symmetry is imperfectly realized or purposefully broken:

> Whenever I look at works of art now, I've been noticing symmetrical patterns and how the artist chose to use them or disrupt them. I think the most interesting thing is balance, the tension between symmetry and asymmetry, in art and in nature overall.

Indeed, in physics, broken symmetries can be almost as important as regular symmetries themselves. Part of the difficulty in explaining these symmetries, broken or not, comes from the fact that they are often not spatial symmetries (like left-right mirror symmetry), but abstract symmetries present in the equations that govern the behavior of matter. With this in mind, we try to get students to synthesize a general definition of symmetry that goes beyond spatial symmetries. Many students spontaneously realize that repeated patterns in time can be thought of as a symmetry. From there it is a short leap to see a general notion of symmetry at play directly in the equations of physics.

[4] Student quotes throughout this article are excerpted from written reflections following MHCAM visits in fall 2023. While the quotes are anonymous, all students have given permission for their quotes to be used.

2. Time: Close Looking

A large swath of physics concerns dynamics—predicting the future—or more prosaically, the behavior of physical systems in time. In the section on time, students start with the common linear notion of time as a sequence of ordered events. They discuss how quantifying time requires periodic behavior. They then consider the unidirectional 'arrow' of time that arises from thermodynamics and how to quantify disorder with the concept of entropy. Finally, the class progresses to special relativity and considers the malleability of our experience of time.

In the museum visit focused on time, linear time is referenced using sequential images of an elk running by Eadweard Muybridge, or a succession of increasingly refined states of working prints by Vija Celmins. Cyclical time is represented in a reproduction of an Aztec stone calendar, while thermodynamic time is apparent in the irreversibly burnt pages of an open volume of Dante's *Inferno* in a photograph by Rosamond Wolff Purcell. Relativistic aspects of time are more subtle, but a conversation about the subjective experience of durations of time can start with the depiction of prison inmates playing dominoes in the image *The Wall, Huntsville, Texas* by Danny Lyon. These aspects of time are evoked using static objects; often the connection is not obvious and a deeper interaction with each object is needed.

A standard, but indispensable, pedagogical technique used in these instances is close looking. Here, groups of students are given the time to contemplate an object, crucially without any label, with the dual goal of noticing details up close as well as seeing the big picture from farther away, and then generating their own thoughts on its meaning. The joy of discovery and the ownership of ideas generated this way make close looking a great active-learning class activity. As an example, used in our unit on time, consider *Multiple Flash Photograph (Bouncing Ball)* by Berenice Abbott, (fig. 1). Students quickly identify this as a bouncing golf ball, but have multiple theories about how the image was created (most think it was digital post-processing before we reveal the date it was made, in the late 1950s). Selectively revealing information, for example that the image was illuminated with a stroboscopic light source, enables students to say much more about the motion of the ball than they might otherwise: it is moving faster when the successive images are far apart, and slower when they are close together. Motion is encoded as distance when time intervals are kept constant. Considerations of motion lead to new observations:

> I liked the way a still photo, like Berenice Abbotts's, can draw your eye in one direction and move you through time. One goal for an artist is to guide the viewer through the piece in a somewhat set way in order for them to understand and have the 'takeaway' you want them to leave knowing. Abbott is able to do this through her pieces in a very literal way which stands out to me. She is able to take advantage of what the viewers know by experience: balls can't get bouncier and a pendulum only oscillates in one big 'swoosh.'

This student has noted that not only does the photograph capture many moments in time compressed into one image, but the natural state of a ball bouncing lower and lower gives us a clue as to which direction the ball was moving in. Another student notes:

> *Bouncing Ball* reminds me of the law of conservation of energy, which states that energy can neither be created nor destroyed; rather, it can only be transformed or transferred from one form to another. This artwork indicates the transformation between the ball's kinetic energy and its potential energy.

Other students then noted that the energy is actually getting smaller as the ball bounces lower. How to resolve these contradictory ideas? The energy is conserved overall, but it is going into disordered sources of energy such as heat and sound. Students readily connected this increase in disorder with irreversibility and the direction of time:

> This piece really captures the movement of the ball and demonstrates how the flow of time has a direction. It also depicts the idea of time reversal asymmetry and how, as time moves toward the future, the entropy increases. Entropy is the measure of disorder of a system.

Overall students found close looking to be very helpful for solidifying the physical attributes of time:

> Time is a hard concept to understand because if you focus too hard on it, you start to lose it. You almost have to loosen up your mind and cross your eyes in order to grasp the depth of time. But, the many different ways that artists have found to convey the different aspects and feelings associated with time are intricate and beautiful—both visually/artistically and through physics.

3. Space Drawing

Along with time, space forms the stage on which physical phenomena unfold. It likewise can be viewed differently from the perspective of different physical theories. Newtonian physics treats space as absolute and linear, whereas space in general relativity is warped and non-Euclidean. The main narrative thread in this thematic section is the roughly concurrent rise of cartesian geometry (and its ability to algebraically describe the position of objects in space) with linear perspective in art. At the museum, students considered perspective drawings from different eras and cultures. To get a sense for how each image was constructed, students were tasked with drawing simple sketches of the art and extending certain lines to see if there was a coherent vanishing point or not. Using this technique, one student noticed some notable differences in how artists used perspective:

> I found it interesting that some of the [artworks] portrayed accurate perspectives converging on one or more vanishing points, while others were slightly off. It felt as if I was able to see the history of the discovery of perspective [in] art arrayed around the room. However, some of the modern pieces broke this pattern and instead distorted their symmetry or purposefully made it slightly off in order to create a certain effect.

Since not all students feel confident in their drawing skills, in the latest iteration of the course, we experimented with a variation of the activity by giving students tracing paper, rulers, and printouts of the works of art enabling them to 'trace' the perspectival lines of each artwork displayed in the museum's classroom. This adaptation made drawing a more widely accessible exercise, and students seemed transfixed by the activity. Using their hands in coordination with their eyes fostered a focused state of attention, and students seemed reluctant for the session to end.

> I'd like to mention a distinct part of this museum visit. We got the opportunity to use the tracing paper in order to comprehend the definitions of space, linear perspective and vanishing points better, to look at the art from the physics side of it. That's when I paid more attention to the existing graphic projections that artists use in their work.

4. Chaos and Determinism: Hypothesis Building

At its core, physics is a predictive discipline. Physicists build models where the future state of a system (e.g. the weather) is completely determined by its current state. Despite the immense complexity of systems (e.g. temperature, pressure, etc. everywhere on Earth), these deterministic models are very simple. In a visit to MHCAM, students explore this idea of complexity from simple rules by critically interacting with examples of generative

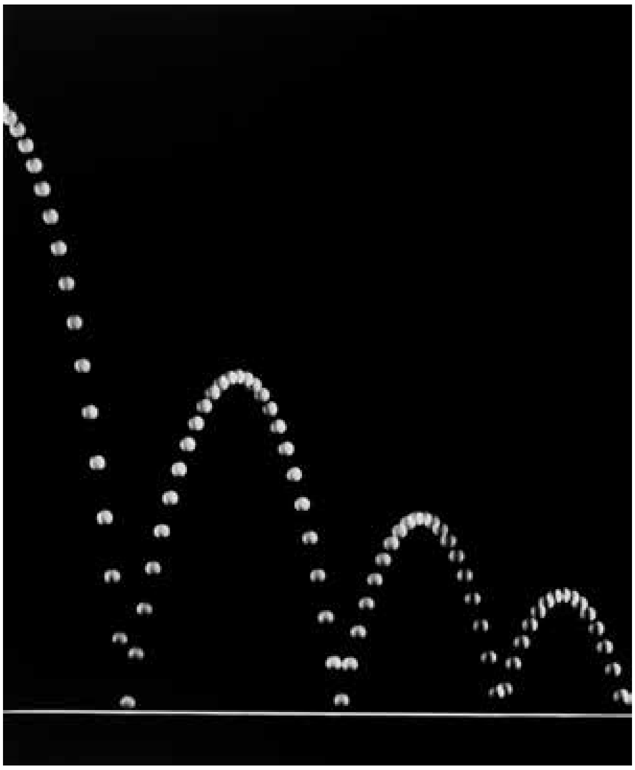

Fig. 1: Berenice Abbott, *Multiple Flash Photograph (Bouncing Ball)*, negative 1958–1961; print 1982. Gelatin silver print. Collection of the Mount Holyoke College Art Museum, Gift of Joseph R. and Ruth Lasser (Ruth H. Pollak, Class of 1947), 1983.21.4. © Estate of Berenice Abbott

art—art which results from a predetermined procedure. In particular, they are tasked with finding the set of rules that generate the observed patterns (red and black bands) in Mel Bochner's print *Range* (fig. 2). Students naturally engage with the iterative cycle of hypothesis building—coming up with proposed rules, checking them against the 'data' represented in the object, refining their rules and repeating the process.

> Mel Bochner's *Range* was fun to examine and try to figure out what rules had governed its creation. There was that level of audience engagement, and I believe that my group and I figured it out, but there could have been more restrictions on the orders of the numbers that we didn't notice. This piece was my favorite because there were bounds on the creative process, but there was still some measure of creativity involved when trying to make sure that the numbers lined up to fit the restrictions. There was freedom within the structure, which I think makes for a fun creative process and outcome.

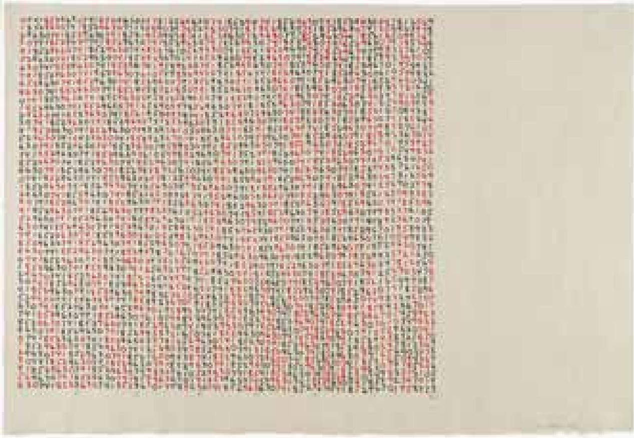

Fig. 2: Mel Bochner, *Range*, 1979. Silkscreen on paper. Collection of the Mount Holyoke College Art Museum, Gift of the Artist, 2015.14. © Mel Bochner

In addition to participating in a very engaging activity, students organically discover the theme of complexity from simple rules.

> I think this piece was so fascinating because it first appeared random and chaotic but if you looked closer it had a method to the madness and a visible pattern. I think this is in many ways a metaphor for the natural world. At first glance everything seems to just be random but slowly we are decoding it by looking deeper through science.

This is a great starting point for discussing chaos—the phenomena of increasing uncertainty despite a completely deterministic system. Given a simple enough example of generative art, students could even modify the rules, create their own object, and observe how the patterns change.

Student Final Projects: Virtual Exhibitions

While only illustrating a portion of the physics topics and pedagogical approaches used during the museum visits, the four examples outlined above show the rich possibilities of employing a variety of active learning methodologies, which can empower students to freely explore what otherwise might seem like intimidating and technical science concepts. One additional and culminating activity is worth mentioning because it has proven to be impactful and popular with students. As a final project, each student puts on their curatorial hat and organizes a virtual exhibition (hosted on a closed course website). A sense of ownership is central to this project, as students choose a physics-related theme and then ten art objects that coherently highlight different facets of this theme. Crucially, one of these objects is chosen from the MHCAM collection, which is then put on display in the museum's classroom during an in-person presentation component of the project. Choosing this object invites students to become proficient in navigating the museum's online database, and provides an opportunity for MHCAM staff to augment the database with novel, physics-based contextual information.

In addition to an introductory paragraph used to frame the exhibition, students write narrative labels for each object. The practice of label writing fosters new skills with a focus on concision and clarity due to a tight character limit and the need to write invitingly for a general audience. To help develop these skills, MHCAM staff host a label writing workshop incorporating the previously mentioned SPS student labels written for the Berenice Abbott exhibition as examples. When the students present their virtual exhibitions to one another during the last two classes, there is a palpable sense of pride in their work as well as delight in the creative endeavor of finding new artworks to apply their knowledge from the course.

Conclusion

This sampling of themes, modes of pedagogical engagement, and student responses showcases several key takeaways learned through teaching a class on physics and art with recurring hands-on sessions at the art museum. Having students respond to carefully selected works of art can create accessible entry points designed to develop their intuitive understanding of fundamental concepts in physics. This in turn builds students' confidence to dive deeper into the technical and mathematical underpinnings of different physical phenomena. As the students themselves reported, works of art provide multiple and varied entry points for considering different representations of both the visible and invisible world, as well as provide thought-provoking examples of pattern making and disruption. In addition, engaging different modes of learning—such as searching for and interacting with art objects, looking closely, drawing, and making hypotheses—gives students agency to make their own discoveries and connect with course materials.

The central objectives of the course are reflected in both the high quality of the final projects and the students' evaluations. These goals include having the students engage meaningfully with important ideas in physics, make connections between science and the humanities, and develop critical thinking and writing skills. As one student summarized: "This course taught me [so] much about the intersection between physics and art. Namely, how themes of symmetry, disturbance, perspective, pattern, and chaos can all be measures to make sense of the world around us. I gained a newfound respect for the arts, in the way that science seeks to reveal truth, I have come to learn that art similarly seeks to model these phenomena in ways that would otherwise be invisible." In addition, there is anecdotal evidence that taking the first-year seminar has subsequently inspired students to enroll in the initial physics sequence of courses, which potentially sets them on a path to become physics majors. In the future, there are plans to survey attitudes and intentions toward physics before and after the course to help quantify this effect and to provide important data for expanding the pipeline attracting students of all backgrounds to consider a physics major.

Acknowledgments

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Why STEM Needs the Arts: A Coda

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In the same year that this volume was realized, the film *Oppenheimer*, which dramatized the life of the titular theoretical physicist known as the father of the atomic bomb for his role in the Manhattan Project, commanded international box offices while the stakes of artificial intelligence entered shared discourse. Comparing the potential of artificial intelligence to the existential threat posed by the Manhattan Project, Tristan Harris (2023) of the Center for Humane Technology cited an AI Impacts Survey revealing that—despite the majority of surveyed machine-learning researchers who agree that the beneficial impact of AI will outweigh any negatives—50% of surveyed researchers believe there is a 10% or greater chance that humans will be made extinct by technology. That's the thing about innovation in STEM: when mass destruction and perhaps even the extinction of the human species are considered possible outcomes, the stakes could not be higher. How might our society support STEM researchers as they navigate such high-stakes decision-making, and process the possible, and actual, impact of those decisions?

There is a scene early in the film *Oppenheimer* where the physicist, then a graduate student, visits an art museum. Oppenheimer casts his sharp silhouette upon several cubist paintings, echoing the German Romantic landscape painter Caspar David Friedrich's motif of the lone man beholding a scene of sublime nature. Oppenheimer then stands face-to-face with Pablo Picasso's 1937 *Seated Woman with Crossed Arms*.[1] The face-off is interspersed with images of stars and explosions, as though to suggest that Oppenheimer refined his study of theoretical physics while admiring Picasso's painting. Oppenheimer did seem to admire Picasso, but his tête-à-tête with this painting likely never happened, since the physicist was teaching as a professor at the University of California, Berkeley, well before Picasso painted this particular work.[2]

Within the context of this volume, the film's inaccuracy might offer an opportunity for a speculative exercise. What if Oppenheimer's encounter with *Seated Woman with Crossed Arms* was not solitary but in the context of a seminar of fellow graduate students? What if at least one woman were present in the room, and she asked about the woman in the painting? What if Dora Maar, the photographer, painter and poet who inspired Picasso as his lover and muse, were acknowledged as a subject in addition to the object upon which Picasso explored the formal possibilities of painting. What if, in this speculative exercise, a museum educator had the ability to pair *Seated Woman with Crossed Arms* alongside another artwork Picasso completed that same year—*Guernica*, the artist's monumental painting of the horrors of war and of the bombing of civilians?

While a solo visit to a museum can be a transformative experience, the film's directorial choices unintentionally illustrate that encountering art as an individual might only reaffirm the beliefs one already holds. To gather around art as a group is to think with a shared object while navigating different perspectives, and it is so necessary to learning how to live in a shared world. As Urry and Simon show in their contribution to this volume, close looking and thinking with Kazimir Malevich's *The Knife Grinder or Principle of Glittering* (1912–13) may begin with an analysis of formal elements or identifying visual cues for time and its passing but could then lead to consideration of the knife grinder as a worker and fellow human being. Interdisciplinary gatherings around art can lead to new research questions, as Orr and Tapia Takaki write, that range from such applications as onboarding artificial intelligence to quantum algorithm devices for collider physics, while also serving as models for community engagement within a university campus.

The essays in this volume offer a primer for crafting bridges between STEM and the art museum, where everything—from the design of the museum visit to the interactive exercises and exposure to diversity of cultures, time periods, and perspectives—is intentionally curated so that learning is collaborative, inclusive, exciting, and welcoming. Such an approach to learning, and to teaching, constitutes an important tool to address disparity in STEM. Many studies over the past decade have examined the factors that contribute to disparity in STEM, not least of which is that students—especially female and minority students—view

[1] The painting is in the collection of the National Picasso Museum, Paris.

[2] See Alex Greenberger, "Picasso Painting Heads to a Theater Near You, Making a Star Appearance in *Oppenheimer*," in ARTnews (July 24, 2023), https://www.artnews.com/art-news/news/oppenheimer-picasso-painting-scene-meaning-1234675202/.

STEM disciplines as lacking in community. Katherine Kricorian et al. (2020) has observe that “women and ethnic minorities remain underrepresented” in STEM, and their pilot study found that the majority (54%) of female and ethnic-minority STEM students surveyed stated that “meeting a STEM professional of their gender and ethnicity would be effective encouragement to pursue STEM.” Exploring why female-identifying researchers often choose behavioral science over STEM careers, Jane G. Stout et al. (2016) conducted a study showing that females tend to perceive STEM disciplines as less “communal.” As shown by the contributors to this volume, community can be cultivated by:

- offering multiple entry ways into the same material to accommodate different learning styles;
- encouraging students to explore and share diverse demographic and cultural factors that contribute to their identities as they see themselves reflected in art,
- fostering collaboration and resonance across disciplines; or
- boosting confidence.

Building community is key to counteracting existing and perceived disparity in STEM. If STEM researchers were more interwoven within academic communities, the pursuit of progress and innovation would not put the future of humanity at risk. Community might offer STEM researchers support for navigating high-stakes decision-making, and a group visit to an art museum could open their eyes to considering how something in the laboratory, or coded within AI, might affect others five, ten, or fifty years into the future. From curiosity to delight and connection, the essays in this volume offer case studies on cultivating a sense of vitality and conviviality within study and research. Curiosity, delight, and dialogue can be antidotes to emotional numbness, which can have a significant impact on mental health, leading to feelings of detachment and apathy.[3] There is a difference between making high-stakes decisions, or any decisions for that matter, while feeling emotionally numb vs. when one feels connected and accountable to others. In addition to helping to address the disparity within STEM, the collaborative and multivalent arts pedagogies practiced across university museums and discussed in this volume can contribute to a sense of connectedness that, though challenging to measure, has palpable consequences for researchers as people navigating a shared and complex world.

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[3] See, for instance, the Harvard Study of Adult Development: https://www.adultdevelopmentstudy.org/.

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