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BECOMING CURIOUS SCIENCE INVESTIGATORS THROUGH RECREATING WITH HISTORY AND PHILOSOPHY

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Introduction

Our curiosity induces us to move into the unknown, to look closer at something and investigate. Curiosity figures in historical and modern practice of science, such as Galileo's motion studies (GALILEI, 1967). This investigatory capacity develops gradually as we interact with the world around us.

Twentieth century psychologist Jean Piaget chronicled this developing process by observing his infants from birth. For example, at 10 months age, Laurant picked up a soap and let it go repeatedly, attending to its disappearance from his hands, but not regarding the soap's next displacements. Two weeks later, his attention had shifted to the released object. Watching its motion, he looked for where it fell, and picked it up, if it fell within his reach. Two days later, while seated in a high chair, Laurant recurrently let items drop off its tray, casting them in differing directions, and craning his body around to see the fall and where something landed. At a year, Laurant's investigatory practice had expanded: he released anything that came to hand, from various positions and heights "in order to study their trajectory" (PIAGET, 1952, p.268-270). By dropping toys repeatedly in different settings and watching trajectories, the child began demonstrating predictions of free fall through his actions to retrieve the dropped toys"discovery of new means through active experimentation" (PIAGET, 1952, p.263).

Curiosity, such as Laurant exhibited in releasing objects, watching their fall, and varying his methods of release and search, is the investigatory means by which science liberates humanity from subjugation under physical and authoritarian controls, in the analysis of US philosopher John Dewey. The scientific outlook, with its response to wonder, openness to exchanging ideas and experimental testing, is a grounding for the practice of democracy, where all perspectives are valued and no individual has more status than anyone else. Yet while curiosity is upwelling in infants like Laurant, it dissipates when children's actions are under constraints, such as are typical in schools. A populace lacking in curiosity leaves people susceptible to manipulation, disinclined to question or to critique their surroundings.

Democracy is fostered through the curiosity of its diverse participants, as they share and develop insights and questions in community. Countering schooling's typical outcome, which erodes children's inherent curiosity, Dewey advocated for an education that nurtures their curiosity. In speaking on the agency of education in bringing about a democratic society, Dewey argued:

> We must develop the scientific attitude — keeping the curiosity alive and directing it into fruitful channels. What we need is the type of education that will start very early to develop the spirit of inquiry, of willingness to weigh the evidence, of experimentation— in short, the scientific spirit (DEWEY, 1935, p.580).

Dewey saw the experience of doing research, of scientific experimentation, as a means of bringing learners to interact with each other and what they study, without being subject to such controls and the exercise of privilege. The act of being investigatory bears authenticity – learners are asking questions grounded in experiences that they develop. Amid engaging with learners who are co-investigators, the ideas expressed by anyone become available to all to be questioned and tested. By putting ideas to actual tests, learners stand to expose failings and uncertainties in what they think and do:

> the whole cycle of self-activity demands an opportunity for investigation and experimentation, for trying out one's ideas upon things, discovering what can be done with materials and appliances (DEWEY, 1916, p.311).

Genuine investigation bears the risk of unsettling authoritarian claims. Investigative work has no space for assertions that certain ideas are to be accorded special status that preempts their full examination on the same investigative grounds as every other intellectual offering. As students collaborate with co-investigators in mutual concerns and pursuits, take up multiple perspectives and come to revise prior outlooks, they are enacting democracy (DEWEY, 1916, p.92-3).

In response to Dewey, I look to trust curiosity as a means of learning for me and my university level students. In the seminar I teach, investigations arise as students consider their own observations alongside materials from historical science and philosophy. The clinical methodology of Piaget (1960) and Inhelder (1974), adapted by Eleanor Duckworth (2006a, 2006b, 2006c) in the research pedagogy of clinical exploration in the classroom, provides the neutral, safe conditions requisite for learners and teacher in embracing the uncertainties and spontaneities that are intrinsic to genuine investigation. These experiences bring us, learners and teacher, together with historical companions in pursuing the science, education and work of our world.

Seminar context

Titled “Recreate Historical Experiments: Inform the Future with the Past”, the seminar that I teach at MIT’s Edgerton Center is an elective open to undergraduate and graduate students of any field of study. Past participants have included first-year students with no declared major; undergraduates in a field of engineering, science or economics; masters’ students in earth science, education or teacher education; and doctoral students in education or engineering. The teachers or teachers-to-be often choose to take this seminar as a means of experiencing exploratory teaching and learning, in this case, of critical exploration in the classroom. Teachers and teachers-to-may be involved with another institution; they come to this class as an educational alternative. Those seminar students who are in science, engineering or some other area, may not have an interest in teaching. They may be attracted to the seminar’s historical science theme and hands-on activities. For these science and engineering students, encountering the unknown in a classroom is an unusual experience that prepares them to face and resolve uncertainties in their future work, in ways they have not been encouraged to pursue before. For teachers-to-be, seminar explorations are provocative for understanding education; they may come to consider these explorations as preparation for teaching.

Class experiences evolve differently each term, with themes and investigations arising interactively among students and me (CAVICCHI, 2011; 2012; 2013; 2014; 2018). This paper relates from how one class, all of whom were graduate students, engaged in historical science, philosophy and arts. This class observed the sky in and out of class, worked with the astrolabe, and discussed readings from ancient astronomy (KEPLER, 1967; SHEN KUO, 2008; ALHAZEN, 1990; SACROBOSCO, 1485; 1532; 1626; THORNDIKE, 1949) to 20th century astronomer Cecilia Payne-Gaposhkin (1984). With fur, silks, balloons, electrophorus and

Wimhurst machine, we explored electrostatic effects described by Gilbert (1600) and Gray (1731-2) and others. We discussed excerpts from John Dewey (1916, 1934) and Jean Piaget (1976) and created experiments in response to these writings. Inspired by seeing marbled endpapers in historical books, we did paper marbling ourselves in class (ARTFUL PARENT, 2017). The class read aloud their own enactments of Galileo's *Dialogue* (2008), Brecht's *Life of Galileo* (2008), and a passage from Marquez (2008) *100 years of Solitude*.

Classroom investigative experiences often originate in a reading or example from history and philosophy. I continually expand the readings and links as the grounds or themes arise – including those suggested by students. In response to the historical or philosophical material, a classroom activity that I did not expect arises. I encourage the investigation in that moment. In subsequent sessions, I support some further extensions of the students' experiences, through providing time for group discussion and review, and through extending the materials and contexts for their activities.

There is no pre-set syllabus. Our activities come about in the moment and in relation to materials and instruments that I introduce and prepare. As I continually research and document these sessions, I prepare daily summaries for my students; these summaries illustrate, excerpt, and demonstrate how learning emerges as we explore together. From researching these records, I developed the narratives related here, as a way of sharing the voices, perplexities and wonder by which learners discover and express curiosity.

Awakening curiosity, encouraging its expression, and sustaining it through whatever may arise in the course of an investigation, is a dynamic process. The teacher is together with students in discovering their curiosity and seeking ways for its development and action. What emerges bears out the educational productivity of trusting curiosity.

Exploring Instruments

At the first meeting of one semester, I placed four historical science instruments on the table about which the class was sitting. I invited the students to investigate together. The instruments included a strobe flash unit from the 1940s, a revolving multiple mirror unit invented by Elmer Ambrose Sperry for A. A. Michelson's speed of light experiments in the 1920s (HUGHES, 1976) and a brass astrolabe modeled on the instrument described by Chaucer (2002). I did not identify any of these instruments, although I provided a laser pointer, balloons, tools and other materials that facilitated working with these unknown instruments.

As the students encountered each other, and the instruments, for the first time, curiosity and questions abounded and evolved into experiments. Student TJ shone a laser pointer at the unit which contained multiple revolving mirrors. Collaboratively joining him, someone turned off the room lights and Jinwen moved a white paper around, to see if she could catch the laser light bouncing off a mirror. After Laura spotted where the laser's light landed on the paper, saying "I see it", TJ set the unit spinning. He asked if they could tell how fast the mirrors were turning. Upon substituting a cellphone light for the laser pointer, broad patches of light appeared and disappeared on Jinwen's paper. Laura exclaimed "it is almost a strobe! Spin it fast!" A means of addressing TJ's question emerged in how the increasing or decreasing pace of the light patches correlated with the rate of spinning of the mirror device. Laura and TJ considered that the instrument might provide an accurate timing or measure. Noticing the name A.A. Michelson on a label on the device and remembering Michelson's research to determine the speed of light, TJ wondered if it was involved in that research.

In exploring this unknown device, the students initially responded to one of its many mirrors by probing with a laser, seeking and identifying its reflection. But the instrument and its mirrors remained static until TJ found a way of setting the rotary mirror unit spinning. Now the laser reflected off each mirror in succession, as it turned past. Use of the cellphone's white light, in place of the laser pointer, accentuated the flashing effect. By likening that effect to a strobe light, Laura inferred the function of the instrument that connected to its inclusion among the apparatus collected by strobe pioneer "Doc" Harold Edgerton, in whose labs our class meets.

While holding the brass astrolabe (as yet unidentified) in their hands, the students were intrigued by the archaic lettering, revolving parts and representation of stars. They conjectured it was to help in finding north.

Having assigned readings on the astrolabe (NORTH, 1974; LIUNI, 2016), at our second session, I invited the class to examine several astrolabes including: an astrolabe of 18 inches diameter, laser-cut from a template (MORRISON, 2010), two 8 inch diameter astrolabes composed of paper and plastic sheet, and the brass astrolabe which was among the unknown instruments at our first class meeting. Intense consideration arose of the instrument, one held in everyone's hand. On the surface markings of one instrument, Gary and TJ identified stars of northern constellation Ursa Major. Looking closely, they came to interpret the North Star as represented by the center pin of the revolving plate marked with stars. Seeing how numbers around the instrument's rim cycled twice from 1 to 12, Gary asked "Did they use a 12 hour clock?"

Amid these collaborative observations of the astrolabe, we were joined by our guest, my former student, architect Francesca Liuni. Francesca shared her spatial and poster exhibit on the astrolabe (LIUNI, 2016; 2017). Francesca's work invites us to contemplate the bounded spherical universe inhabited by the historical users of the astrolabe, in contrast to our present universe of indefinite extent. Where the astrolabe surface is two dimensional, Francesca's architectural work is sculptural and three dimensional. The students considered how it could be that the three dimensional sphere of the heavens comes to transformed into the plane of the astrolabe. Francesca's architectural diagrams projected the sphere universe onto the planes of plan and cross-section. Emulating the diagrams, a student drew circles of longitude on a clay ball with a marker. Smashing the clay ball, the flattened markings resembled the astrolabe's grid lines.

Moving between 2-D and 3-D in Depictions of Heavens as a Sphere

The following week, as an example mediating the sphere of the heavens and the astrolabe's plane, I arranged for a visit to the school archives to view three early printings of a medieval work, Sacrobosco's*On the Sphere* (SACROBOSCO, 1485; 1532; 1626). The illustrations – and the historical volumes – evoked curiosity, wonder, and realization from two students, Summer and Gary.

Touching the historical pages with their own hands was awesome for them. Summers' gasp at the beauty of the Sacrobosco's endpapers inspired me to develop a later session doing the craft of paper marbling. While the paper marbling activity was new and daunting for me to undertake to set up, the students were intrigued in the drama and beauty of the effects and patterns that they produced on paper[72].

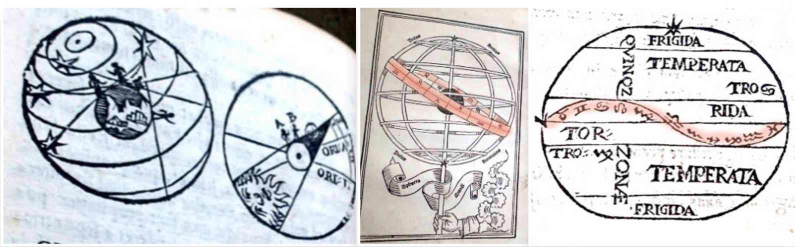
Seeing people portrayed standing on a circle representing earth's surface, radially oriented – appearing upright near the pole, and sideways near earth's equator (Figure 1, left), Summer, a Harvard education student from China, expressed her deep wonderment that ancient peoples realized the sky was the same, in China and Europe. Gary, a student in MITs Advanced Study program, asked whether ancient China had analogues to

72 Artful Parent (2017). 6 Easy Ways to Marble Paper. https://artfulparent.com/how-to-marble-paper/

constellations. Later, we viewed star charts of medieval China (Needham, 1954) and Orion rendered as a boar trap among indigenous people of the Philippines (AMBROSIO, 2010), shared by classmate TJ.

Two diagrams figured in the activity that arose as a development from our viewing of the volumes of Sacrobosco's astronomical work. One (Figure 1, middle)), Sacrobosco's frontispiece, evoked Summer's exclamation: "a god hand revolves the universe like a toy!" The other diagram (Figure 1, right) depicts sun's path in that universe as a tilted band (here colored in red), is overlaid on a two-dimensional portrayal, where regions of the earth are depicted in relation to it.

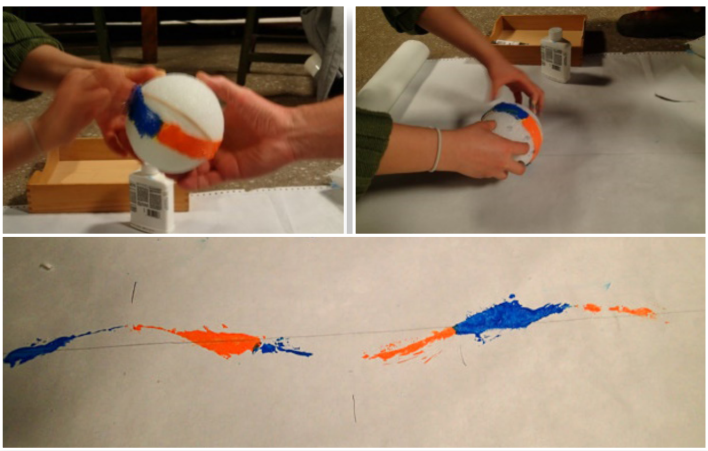
Figure 1. Left: People standing upright, approximately radially, on a circle that depicts the earth, within a larger circle that represents the sphere of the heavens. Middle: Sacrobosco's frontispiece, where a "God hand" revolves the heavens around the central black ball of earth. The sun's path is represented by the zodiacal band, highlighted in red. Right: The sun's path across a year (highlighted in red) is overlaid on a two-dimensional diagram of earth



Back in the classroom that afternoon, we resumed with an ongoing project of producing geometrical constructions on paper by following Euclid's *Elements* (EUCLID, 2002). Gary brought out a large paper, from his other class, marked with a Spirograph. His sense of its relation to our astronomy provoked me to a possibility I had not envisioned before: creating our own version of

Sacrobosco's universe diagrams! I gathered potential materials while Gary and Summer viewed digital reproductions of the two illustrations that intrigued them (Figure 1 middle and right). One represents earth and heavens as a sphere; in the other, the earth is flattened on a plane.

Figure 2. Left: applying blue and orange oil paint to the Styrofoam ball [representing earth], along a band that represents the zodiacal path of the sun. Another band on the ball represents the equator of earth. Middle: rolling the ball onto a sheet of paper, marked with a straight line. The ball is rolled so that the equator band matches up with the line on the paper, as it is rolled along. Right: the curve produced on the paper, by rolling the ball marked with paint. The curve resembles the zodiacal line in Figure 1 right.



The project emerged of going from a physical 3-D sphere – a large Styrofoam ball- to the 2-D plane. The styrofoam ball was encircled with rubber bands. One rubber band served as an analogue to the equator. A different rubber band, tilted with respect to the equator, represented the zodiacal band. Oil paint was dabbed on the rubber band of the zodiac by Summer (Figure

2, left). In the process of applying the paint, she initiated the idea to divide the paint in 4 parts, using two colors of paint, blue and orange. Rolling the ball's rubber band equator along a penciled line (Figure 2, middle), evoked suspense: how would the paint on zodiacal band mark the paper? The painted dots that were produced exhibited a curve that dipped above and below the pencil line of the equator. Gary interpreted the painted curve (Figure 2, right) as the year. Its crossings with the pencil line were equinoxes; solstices at its peak and dip.

Saying he was surprised by the day we examined a globe of the earth in class, with its support showing the earth's tilt, Gary proposed to place the zodiacal band at a yet more extreme angle (as compared to the equator rubber band). To this curiosity, Summer added her own innovation: to place paint dots at 12 positions along the band, in analogue to zodiac, and in alternating blue and orange colors. On Gary's first roll, only the dots nearest the equator marked the paper. Upon repositioning the rubber band equator at a lesser angle from the band, a few more dots hit the paper. Exclaiming that it made sense, Summer drew in the curve's missing parts with a pencil.

In reflecting on this activity, with the astrolabe alongside her, Summer wondered if the peoples who invented it, and Sacrobosco's book, believed that the sun moves, not the earth. Her contemplation reveals the depth to which these investigations move her thinking, as she comes to experience and express historical perspective differing from ours. Extending that perspective-taking to the entire solar system, Gary wondered, "What if we made 8 astrolabes, one for each planet?" Wonderment emerges about the scale of the solar system in the universe.

In this example, the students' curiosity with Sacrobosco diagrams opened into recreating history, and their own understandings of it and the universe. Further investigations interweaving space and history, experience and observation, included observing daytime moonrise, exploring historical and current climate data projected on a sphere globe, viewing historical marbled paper and then marbling paper together in class. From the Sacrobosco activity, when Gary contemplated an astrolabe for every planet, he went on to construct astrolabe geometry by hand, and to code and design the tympanum for 8 astrolabes, producing a project that surprised everyone!

Dewey's Philosophy invites an experimental activity

An ongoing activity for this class involved discussing John Dewey's writings. During one discussion, the same passage was selected for reading aloud, by Dima, a teacher at a Waldorf school who joined us that day, and Gary. There Dewey identified a role for education in developing the "personal initiative and adaptability" as essential to participants in a democratic society:

> A society which is mobile, which is full of channels for the distribution of a change occurring anywhere, must see to it that its members are educated to personal initiative and adaptability (DEWEY, 1916, p.93-4).

The undoing of walls and divisions between people, for Dewey is inseparable from the deep and philosophical work of integrating mind and body, thought and experience. To do this work as education entails having the learners be the ones who are observing and inferring relationships – where these relationships interweave all manner of physical, human and intellectual domains. Drawing thought into engaging relationally with the world is the incipience awareness of uncertainty, instability, risk-awarenesses that learners are to be encouraged in extending investigatively.

Each classmate spoke from a compelling personal experience of integration. Gary thrilled to Dewey's example of a child flying a kite:

> The boy flying a kite has to keep his eye on the kite, and has to note the various pressures of the string on his hand. His senses are avenues of knowledge not because external facts are somehow "conveyed" to the brain, but because they are used in doing something with a purpose (DEWEY, 1916, p.149).

TJ and Dima marveled at the complex coordination entailed in catching a ball. Dima spoke of synchrony that emerges with another dancer in doing contact improve exercises; violinist TJ of the enthralling upwelling of sound when an orchestra tunes. Summer expressed "Allow yourself to arrive" in an experience. Responsively in that moment, I proposed that for the remainder of our class, we might create together such an experience.

While I had no specific activity in mind, immediately, Gary asked for a fan, to try indoor kiting. As I went off for a fan and light materials, Gary sketched on the board. Proposing that the fan's effect would be related to its distance from something (Figure 3 left), he exclaimed "I don't know". With the fan unplugged, Dima enacted her hunches that the relation would be gradual, not abrupt. Upon starting the fan, Dima confirmed her hunch: a blue paper held near the fan was horizontal; it hung down when distant.

Figure 3. Left: Gary's blackboard diagram proposing either a linear (line rising to the right) or nonlinear (curve rising to the right) relation between the force or effect of the fan on an object, and the object's distance from the fan. Middle: Summer holds a strip of flimsy mylar beside the fan (left of the frame of the photo) and it stretches out in the breeze. Right: After repositioning the fan to blow vertically, Gary holds the mylar strip over the fan. The strip stretches vertically upward, eventually breaks loose and is held in the ceiling.

A flimsy mylar, among light materials I'd gathered, astonished everyone. Upon release before the fan (Figure 3 middle), it traveled, fluttered and even hung seemingly in place. Exclaiming with awe, everyone was perturbed in their thinking. Was its behavior measurable? While Gary persisted with his distance-effect theory, Dima advocated greater complexity: "it changes as it moves!" Repositioning the fan to orient upwards, not sideways, Gary modified the apparatus to address his emerging questioning, thus pitting the fan effect against gravity (Figure 3 right).

Now the mylar sailed to the ceiling and lodged there. A new improvisational research into the mylar's behavior ensued in the effort to retrieve it. Amid the celebration of the mylar's descent, I invited reflections on this experimenting, as an intermingling of experience and reflection in Dewey's writing.

Reflection on History and Philosophy in encouraging students' curiosity

In these examples, passages of history and philosophy came to life through students' openness in acting on curiosity. Learners' personal reflections coordinated multiple perspectives in relationship with the universe, including Summer's "arrival" in meeting ancient peoples' geocentrism and Gary's construction of planetary astrolabes. Learners' differing perspectives deepened collective experimenting - such as Summer's idea to paint the ball in parts, and Dima's attention to mylar's changing shape-, and collective discussion - such as the concurrence of Dima and Gary in reading aloud the same sentence from Dewey, and the diversity among experiences of mind - body synchrony, ranging from kite-flying to an orchestra's tuning. History and philosophy as works of life are ongoing through us taking up those works into investigative experiences of reflection and community.

In reflecting on these experiences, Summer, an education student, concurred with Dewey that education can kill curiosity. In her final paper, she wrote:

> How can we cultivate the children's curiosity?
>
> For me: You never have to cultivate curiosity in children... The only problem is not to kill it. Elizabeth showed us well how to not kill the curiosity.
>
> I can imagine how (people lacking in questions and curiosity) were discouraged when they themselves were young children with many questions. This is the most cruel thing for me in the world: killing other people's inherent ability or rights utilizing our power, such as life, freedom or curiosity. In my opinion, educators [who] discourage children's questions do unforgivable behavior (XIA, 2018)

There is an alternative: education can welcome curiosity. Summer and her classmates celebrated their experiences of collaborative, shared curiosity. Curiosity reciprocates educators' trust, trust in learners' questions, taking them into unknown, places of learning together with historical thinkers and investigators.

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