Time Traveling – Intuitive Grasp of Time Takes Time

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Introduction

How do we tell time's passing from what goes on around us? We seldom 'take the time' to notice everyday indicators of time. Three students and I set out to observe those features for ourselves during the fall of 2010. Our observations integrated with history and fiction, moving into both past and future.

At our first session, the Time Traveller of nineteenth century author H.G. Wells [1895] introduced my class to his machine as we viewed a dramatization [2002]. The Time Traveller was setting off into the unknown, and so were we, although by a different means. In place of the Traveller's physical machine, we employed the pedagogy of critical exploration while getting from one time to another – whether those times were historical, or occurring within our sessions. This pedagogy put the students and me into roles like that of Wells' original Traveller where we did not know what would come next, while unlike those of the movie's actor or students in a conventional classroom, where scripting prefigures plot and outcomes. Like the Traveller, we learned through our own participation with multiple expressions of time that originated in science and arts.

Time traveling accommodates a journey that is not sequential. This paper narrates the observations of time, instruments, and history that arose as the class explored time through outdoor shadows, night sky observing, and mechanical motions.

Critical Exploration; Teaching Beside Reconstructing Science and History

Critical exploration in the classroom is the research pedagogy developed by Eleanor Duckworth(2001, 2006c, 2006d, 2006e, 2009) from origins in the work of Jean Piaget (1926/1960) and Bärbel Inhelder (1974) and the 1960s Elementary Science Study (ESS 1970). It applies the quest for understanding of a researcher to spontaneous interactions evolving within a classroom. Through closely following whatever transpires in students' activities and thoughts, the teacher seeks to further students' relations with each other and the subject. The teacher supports students in satisfying and developing their curiosities, which often results in exploring the subject matter by routes that are novel to both teacher and student. Teacher and students mutually sustain, extend and challenge each others' exploratory endeavors. They do this without relying on explicit or implicit "answers" that the teacher gives or that students are asked to provide (Cavicchi et al. 2009, Duckworth 2009).

Most learners struggle with the issue of answers. The critical explorations teacher builds a classroom where it is safe to express tentative ideas and where students' effort for understanding is not reduced to finding answers. Exploring one's own ideas leads to unexpected complexities; participants find themselves in confusion even about matters they previously considered to be elementary (Duckworth 2006b). Facing complexity and confusion is encouraged as an opening for personalized student investigations. Teachers document explorations as a research process and as a source of emergent curriculum. Narratives based on these classroom experiences demonstrate what emerges through learners' exploration across subject matters including: floating and sinking (Duckworth, 1986/2001a); batteries and bulbs (Cavicchi, 1999; Hughes-McDonnell, 2000); paint and brushes (Chiu, 2003); teacher education (Duckworth, 1987/2006c; Magau, 2001); a poem (Schneier, 2001), nineteenth century butter molds (McKinney, 2004).

Critical exploration is particularly suited to introducing students to the blend of science and history that arises when students reconstruct experiments and instruments of the past through their own experiences. Researchers who redo past experiments find themselves thrust into genuine uncertainty about practices that are not evident from textual records (Heering 1994, 2008; Settle 1996; Tweney 2005, 2006; Weber and Frercks 2005). This absence of ready-made answers about historical science, along with its human story, draws students into experimenting as detectives and investigators (Heering 2000; Klassen 2009).

The teaching experiences discussed in this paper are taken from one instance of a laboratory seminar that I teach at MIT titled "Recreate Historical Experiments: Inform the Future with the Past" (see SP713 and SP726 in the MIT Open Courseware site MITOCW 2002-2011).[1] Class sessions involve explorations of physical phenomena and history, such as: electricity, magnetism, water, sound, optics, and microscope observing. A unique story of exploration, discovery, and curriculum development arises in each run of the course (Cavicchi 2007, 2008a, b, 2009); time was the overall theme for the semester presented here. Course experiences include lab activities, reflection and notebook assignments, historical materials viewed in the classroom and during museum and library visits, and sessions with guests. Participants include undergraduates at all levels and graduate students; there is no prerequisite.

Two undergraduates enrolled in this fall seminar term on exploring time. Jesse was a senior in mechanical engineering; Niobium was beginning her freshman year, having arrived to the US two weeks before. Yang, a first-year doctoral student, joined us from Harvard, where she learns the research practice of critical exploration with her adviser Eleanor Duckworth. Yang took on a teaching role during several class sessions and with her other colleagues.

Outdoor Shadows

During our first class, we rode vicariously with H. G. Wells' Time Traveller in his brass and steam machine via an excerpt from the 2002 movie. Changes between light and dark sped up at an ever-quickening pace across a day, a year, and centuries into a distant future. Afterward, Jesse shared a hiking experience, by which he came to realize time's passing is meted by light and dark. After dark:

> it got darker and then black. I thought about how our lives are structured around the sun. You see the world in a different way, by that cycle.[2]

Across the fall, that cycle engaged us with deepening awareness of its changes.

One sunny mid-September afternoon, we went outside. I suggested:

> Look around you. Describe and quickly sketch what you see. Consider areas of light and dark. Consider boundaries.

Something different caught each student's eye. The three students became so engrossed as to draw thoughtful, detailed sketches. On coming together, I asked for:

> your impressions, what you chose to look at.. what you noticed and thought.

Where a tree's loose foliage shaded grass, Jesse discerned: "different levels of shadow…[some] fully lighted, [other] fully shadow" (Figure 1, Left) By contrast, he drew a pillar: light divided from dark along a distinct line. Unlike the tree shadow's patches, he saw the area within that pillar's shadow as "uniform" (Figure 1, Next). As Jesse held each sketch before us and what he viewed, we saw his sensitivity to gradations in the lawn and forms cast by the stone. While the shadow line was already different, this side-by-side comparison of sketch and scene allowed us to share his *act* of observing, not just the later record of it.

Yang actually drew on a pillar! With green chalk, she drew along the edge of the shadow of the pillar's fluting, cast within its groove (Figure 1, Middle). Twenty minutes later, that edge had shifted rightward; she marked it in white. After another twenty minutes, she marked the new shadow. Together we examined Yang's marks. Were these spaced equally? Since a ruler could not fit into the curved groove, they placed a string within, marking each segment (Figure 1, Middle right). When straightened, the string payed out these intervals as similar.

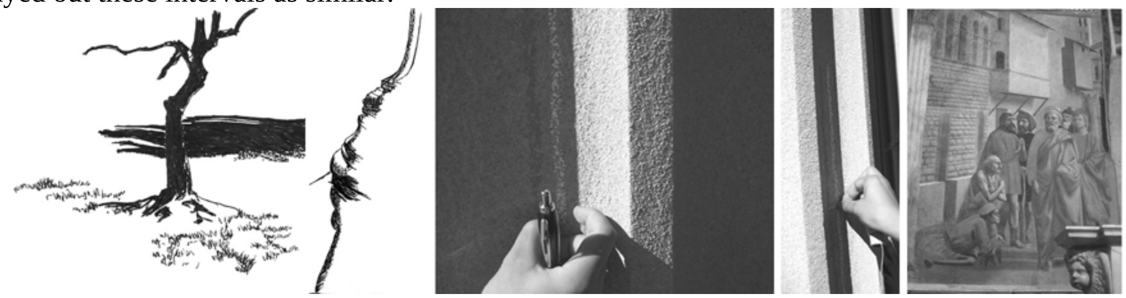

Figure 1. Left: Jesse's drawing of a tree; Next: Jesse's sketch of the light/dark line at a pillar; Middle: Yang's chalk marks at the pillar fluting's shadow; middle right: using string to measure mark separations; Right: Masaccio's "St. Peter's Healing Shadow", Brancacci Chapel, Santa Maria del Carmine, Florence.

The act of drawing opened up acute observation of shadows in gradations, form and position. This multifold character of noticings had profound implications for our study of time. It meant there would not be just one way by which the students would look to associate their shadow observations with time. Each sunny afternoon when we went out again, further findings emerged in an exchange that integrated with other experiences we developed and shared.

Remaining on the pillar all term, Yang's chalk marks continued to reveal more. Two days later at the same time, the fluting's shadow aligned with Yang's green mark. Many overcast days followed. A month later, the fluting's shadow was distinctly left of her mark. On marking that edge in another color then, and twenty minutes later, the interval was less than in September. Jesse construed motion and time at the grand scale of astronomy:

> if we had exactly equal time intervals, I think we could calculate the angle that the sun is moving, over the month.

Using a different set of shadow marks, Niobium inferred how the sun's path was changing as the fall season proceeded. She said

> … I think it[shadow] is going up. To tell [how the sun changes] you stand there and you can see the sun. [Then you go there again at the] same time: you see the sun is kind of more level with you. So I think the sun is going down.

One cloudy day, we extended our experience with shadow and drawing by responding to a reproduction of Renaissance artist Tomasso Massacio's 1426-7 fresco "St. Peter's Healing Shadow" in the Brancacci Chapel of Santa Maria del Carmine, Florence (Figure 1, Right). The students pondered relationships among shadows and figures, time and the story. Responding to Jesse's observation that these shadows seemed very long, Niobium proposed where the light source might be. Yet Jesse perceived a paradox about light on the kneeling beggar, saying "His face is lighted even though he seems to be in the shadow! Of Peter." Yang noted that some figures actually lack a shadow. Jesse's sense that the buildings seem more "3-d" provoked discussion of figures in that constructed space. Yang put herself into that street, exclaiming: "the house is too small!" This consideration of spatial relations brought Jesse to identify an embedded time sequence, germane to the artist's narrative: "One beggar is down, the next is getting up, the next is up and they are getting stronger.." Stepping into Massacio's fresco had us, like Wells' Time Traveller, bringing together multiple forms of evidence, some physical, some not, in iteratively apprehending both the painting's past and our present understanding.

Having taken the time to observe shadows, the students gained an intuitive feel for what was happening. The cycle of light and dark, sensed by Jesse on a hiking trip, took us from fall to winter, and from our day to Massacio's. That cycle emerged as complex, yet the students responded collaboratively, developing their observations and ideas. No external explanation targeted their studies; rather, what transpired in class reached expansively, generating new experiences that expand what we observe.

Motions of the Sky

From long ago, people followed seasons and found time at night by tracking orientations of stars. Such lore is uncommon now. City lights so outshine the starry array that our lives go on unaware. Hoping to open that world—and evidences of its time cycling—to the class, I encouraged everyone to observe the night sky visually. This informal seeing proved a challenge. During the first month of class, neither undergraduate shared a nighttime observation. Finally, one month in, Jesse described a beautiful sunset displaying "pink on [airplane] smoke". In rejoinder, Niobium reported that out her dorm window at night, she saw only airplanes.

Wondering what else she might notice at night, I asked where her window looked. I tried to internally picture the portion of sky met by Niobium's window. She offered that her dorm had a common room on its topmost floor. By our next meeting, Niobium had been up there. With breathless poetic intensity, she relayed the many outlooks, having what she called "layers":

> …from the dark sky down to the high buildings…to the trees standing along the river waving in the wind…every layer is like a different world.

A few nights later, Niobium, recorded her first observation of the moon (several days before full). Perhaps her tower investigations affirmed her in relation to observing distant lights of night.

For Yang, my curiosity for Niobium's window view gave rise to another kind of observation. Speaking to me, she reflected on:

> You were imagining the window view with her. It is just very encouraging. The window is there…very sensitive on your part, when you imagine with the learner together. I can see those moments. Of opening the possibilities, for us.

For a teacher to look through a student's eyes, sharing her window view in the mind while seeking what might be out there, was for Yang an example of the teaching she aspires to express.

The clear night of October's full moon, we gathered at the courtyard with tubes, tripods and small refractor telescopes. The moon was prominent, with Jupiter higher and to its right. We began looking.

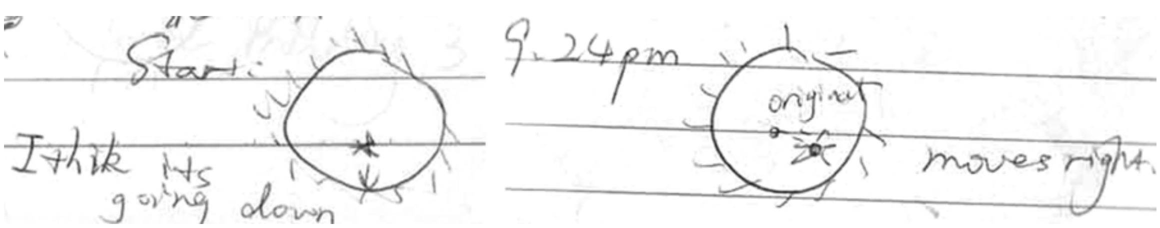

Figure 2. Left: Niobium's first sketch of her view of Jupiter [star] viewed through telescope tube [circle] and her sense that it moved down. Right: Her next observation begins with Jupiter in the center ["original"] and records it going "right".

Taking an empty tube affixed to a tripod (Cavicchi 2010a), Niobium viewed Jupiter. Soon Jupiter slipped away from that tube's view (Figure 2, Left). Her response expressed genuine curiosity. She reoriented the tube to center on Jupiter. Every minute, she sketched where it appeared, relative to the unmoved tube's circle. Within five minutes, Jupiter was gone again, displaced rightward (Figure 2, Right). Now repositioning the tube to put Jupiter at the far left, she charted it every two minutes. Repeating this sequence once more, she came to predict its positions (Figure 3). With each pass, Jupiter went right.

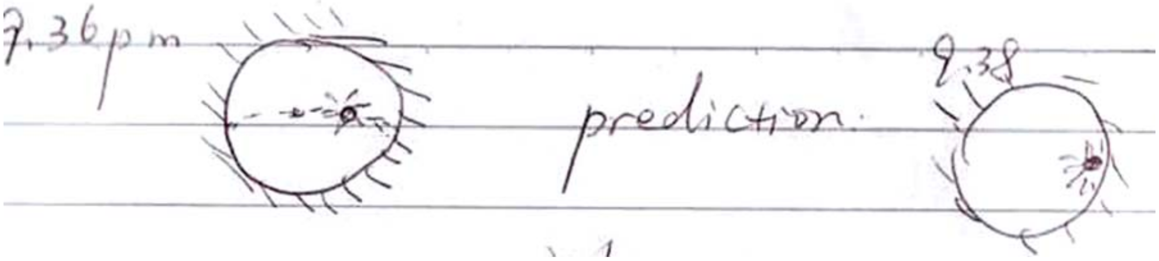

Figure 3. Left: Niobium's sketch of Jupiter's paths as she observes it through the tube. Right: Her prediction of where it will be 2 minutes later.

Nearby, Jesse was handling a telescope[3] for his first time. Holding it in his hands as a spyglass, he gazed into the dark. After mounting it on a tripod, it remained challenging to capture the moon in the telescope's view. Amazed by what he saw, he sketched its features (Figure 4, Left), inferring evidence that its light comes from elsewhere and dismantling his childhood belief that the moon glows of its own. As for Niobium with Jupiter, the moon soon left the telescope's view. On reorienting it, Jesse watched with surprise and attention to see how the moon went. His sketches recorded the moon going left and down (Figure 4, Middle).

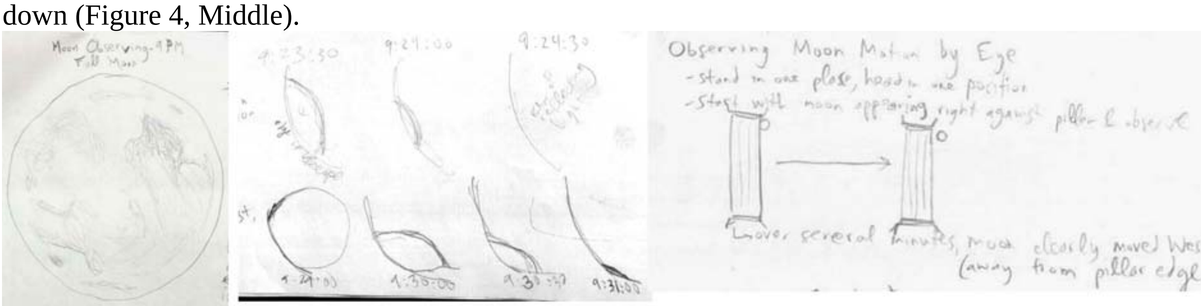

Figure 4. Left: Jesse's first telescopic sketch of the full moon. Middle: Jesse's diagrams showing the moon slipping to the left and below the C arc of his telescope view. Right: Jesse's diagram depicting observing the moon while he aligned with it and a pillar – it moved right.

What is going on with the moon? Standing together, Jesse and Yang gazed at the moon with their eyes. It was hard to distinguish any change. The pillar again proved convenient. Yang and Jesse aligned their heads, a pillar, and the moon. They watched. (Figure 4, Right) Would the moon go right and emerge from the pillar, or left into the pillar? On their first trial, the moon went left. Yang wondered: "Am I keeping my head steady?" Fetching a chair, Yang lined herself with pillar and moon. Sitting very still, the moon seemed to go right. The ambiguity of making this observation gave her pause. There was so much to investigate: "I didn't record even how long it takes".

Later, we pored over everyone's notebooks. Niobium shared astonishment that sky objects move, saying

> Actually we see the moon moving up! [*with surprise*] Jesse saw the moon moving down; we saw the moon moving up.

On his part, Jesse ascribed that discrepancy to unsteadiness in the mount, and sought a "fixed reference" [Thornburg 2010]. The undergraduates' persistence in recording *whatever* they saw moved Yang, whose notebook entry was cursory. She reflected:

> I am stunned by their drawings … their bold, fuzzy, messy, and dense strokes. …Dare I draw? (Yang 2010)

The dilemma between the observations of Niobium and Jesse about the moon's motion intrigued Yang. Borrowing a telescope, she assembled it herself. One eyepiece showed everything upside-down, but not the other. Curious to for her classmates to use these instruments to probe the seeming opposition between their observations of the moon's motion, during the final week of class Yang led us in an exploration with telescopes during daytime. Observing moving clouds both with, and without, the telescope gave them an immediacy with the inverting effect of lenses on the sense of motions.

MIT astronomer Amanda Bosh, who met us for later rooftop observing sessions, had never used an astrolabe (North 1974), a historical sighting tool of which the students had a modern reproduction (Morrison 2010). When the astronomer identified Altair, a bright star marked on its rete, they measured its angular height with our homemade quadrant. Then, orienting the astrolabe for that star's height and the date, they read the time at night as predicted from the astrolabe's outer dial. It was within a half-hour of the time on Niobium's watch.

While doing this astrolabe activity, Jesse conceived a contrast between the experience of time in our day and that in the past. Today it is easy to get the time, but we seldom see or know the stars. Perhaps the time that is so readily available can initiate us into apprehending stars, whereas in the past, keen observation of stars laid the grounds for computing time. Jesse suggested using the astrolabe in reverse:
I think that measuring time is very accurate now but people don't memorize the stars, as much. So maybe [we] could set the [astrolabe to the known] time and [use it to] find an angle, to a star.

Jesse's realization applied not just to the astrolabe, but also to our overall effort to form a personal sense of time through witnessing the night sky. To begin to grasp how the sky reveals time, we had to discover that night sky for ourselves. Even seeing it at all, beyond airplanes and city lights, remained elusive – until Niobium went up the tower and became entranced by her present night-time surroundings. The bright objects beyond our horizons – the moon, Jupiter, stars—exhibit appearances and motions of their own. While unknown to us, these patterns are at play whenever we look with our eyes and become more evident with the aid of instruments such as Niobium's tube, Yang and Jesse's pillar, the telescopes and astrolabe. Yang gained the awareness to express an observationally rooted trust that was missing from all our previous encounters with the sky, in writing:

> Before [taking this course], I know that the Moon moves across the sky everyday, but I never thought that I can see the movement of other stars (or objects in the sky)! I thought they move pretty randomly. (Yang 2010)

For Niobium and Jesse, having experiences due to earth's daily motion relative to distant objects came as unexpected and yet something that drew their curiosity to follow in self-initiated observations.

Our seminar's underlying theme of time accentuated the provocative character of these personal experiences. Whatever our personal paths of wonder, confusion and awe with the night sky, a meaningful connection arose for each with relationships, patterns and cycles that operate in the sky above us, were known to people in the past, and yet are mostly absent from everyday life today. And as Yang reflected about my imagining of Niobium's window view, the teacher's role lay in envisioning at the side of each learner, with all that vast potential before us.

Mechanical Motions

Repetitive motions naturally elicit a sense of time. To open our observation of mechanical periodicities, I assigned students to visit MIT Museum's gallery of the kinetic sculptures of artist Arthur Ganson (2009-). Ganson's playful contraptions of delicate hand-made gears, whose motions suggest human qualities, fascinated everyone. Niobium filled her notebook with intricate drawings (Figure 5) as she set out "to see which part is moving at first." (Song 2010) Astutely appreciative, Jesse felt moved:

> Seeing how he makes the gears, cams, and counterweights himself, with such whimsical and ingenious results, inspires me to be a more innovative engineer. I want to be an artist, an

> inventor, and a researcher rolled into one, so his example thrills and inspires me. (Thornburg 2010)

Joining our class one day, the artist described how his individual pieces evolve through an experimental process. His passion for exploring and intuition for time marveled us. Ganson said:

> The essence is to be in the investigative, designing, exploration mode…Time is fundamental…I started to make machines because I was interested in how it evolved over time…How is this changing?! I want to expand time and slow it so I can almost spend forever in each moment!

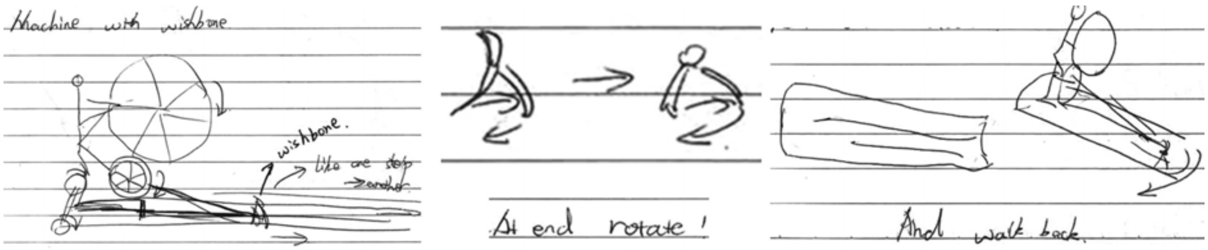

Figure 5. Niobium's sketches of the successive motions of "Machine with Wishbone", a kinetic sculpture by artist Arthur Ganson, exhibited at MIT Museum.

Gears are central in mechanical representations of time; I prepared diverse class opportunities for exploring with gears. Outside of class, I invited two school-aged boys to make something using a LEGO kit with gears. Posing the boys' finished constructions to my students (Figure 6, Left), I asked what they noticed – and encouraged each to construct one. Neither undergraduate had played before with these materials. Jesse, as keenly receptive to elegance in the boys' engineering as in Ganson's, fashioned a multi-axle geared response (Figure 6, Next). Working through many mismatchings, in Niobium's accomplishment a turn in one direction transmitted to a crosswise rotation (Figure 6, Middle).

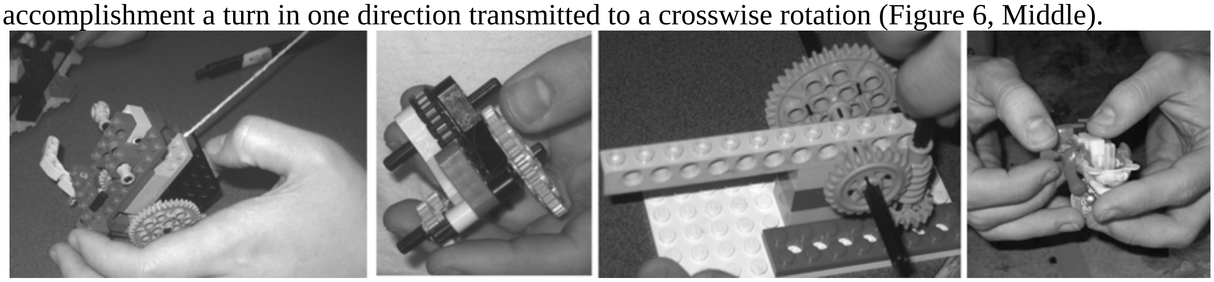

Figure 6. Left: LEGO construction with gears and pull-string, made by a boy; Next: Jesse's LEGO gear assembly; Middle: Niobium made one gear turn another at right angles; Right: disassembling a wind-up toy.

Wind-up toys and mechanical clocks furthered our investigations with gears. The students sent wind-ups of differing actions scooting across the table and chose one each for close study, sketching – and disassembly! (Figure 6, Right) Tiny plastic gears internal to these toys resembled gears within an alarm clock that we also opened. Were the number of teeth on a clock gear operative to its time-keeping? With a hushed intensity equal to a surgeon's, the students counted and recounted the gears' minute teeth and sought out patterns. It fascinated them how their detective work with a clock of today echoed the analyses of scholars who seek to understand and reconstruct the Greek Antikythera mechanism (Field and Wright 1985a, 1985b; Seabrook 2007; Wright 2007).

Our highlight in mechanical explorations involved a replica of a historical clock movement built by instructor Tony Caloggero.[4] Mounted so all parts are visible as it runs, Tony welcomed us to observe. Its complexity amazed everyone (Figure 7). Even Jesse had never before examined the inner workings of an operating clock. Seeking out interrelating gears in the continually proceeding works, he tracked some with understanding and others with puzzlement, saying:

> Every level is gearing it down, so the next one goes much slower. The big one turns the small one, this to small, this to small, this to small…I don't see what this little L shaped piece [does] …

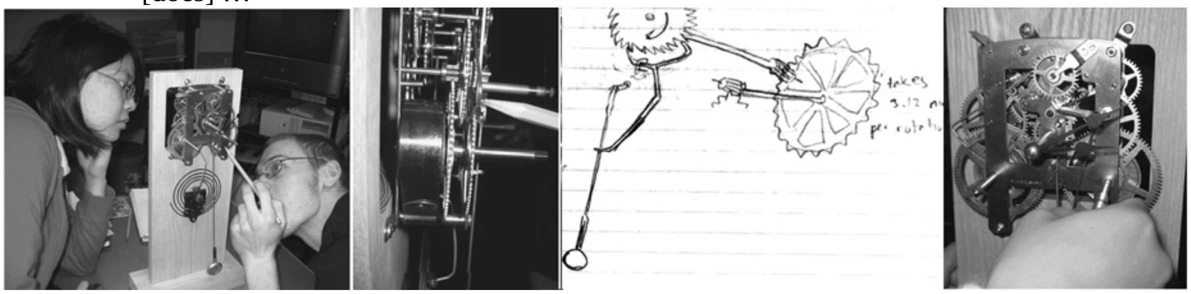

Figure 7. Left: examining Tony's clock; Next: the gears edge-on; Middle: Jesse's diagram; Right: the clock's hands.

By watching through many cycles, sometimes intervening to stop or advance the movement, the students were enmeshed in studying its intricacies and cheered in anticipation of its cleverly governed chimes. Another time, Niobium observed as Jesse and Yang applied their dissection of an alarm clock to consider how the gears in Tony's clock properly advance its minute and hour hands. Niobium not only grasped their inferences about the mechanism, she also witnessed the process of their discovery. In observing her peers, she felt herself:

> …deepen the understanding towards others' thoughts and words and sometimes even grasp the person's implication through their actions. (Song 2010)

This respect for the thoughts and actions of others conveyed to counterparts of other times that the students met by time traveling. Brian Selznick's beautifully illustrated children's book *The Invention of Hugo Cabret* (2007) introduced us to a boy who maintained clocks and reconstructed a mechanical automaton (Maillardet 1800). Together we experienced the "magic" of stop-action photography of that fictional boy's mentor, pioneer filmmaker Georges Méliès (1902, 1907). Captivated by the science fiction of H.G. Wells and Jules Verne, Jesse and Niobium addressed their final papers to these authors. Jesse playfully depicted himself as now stuck in the nineteenth century and in need of the Time Traveller's machine to return to his own environs. Expressing fervent empathy for another fellow adventurer, Niobium greeted Captain Nemo via their common companion, Time. By contrast, addressing the future not the past, in the form of the boy who made the Lego gear project for us, Yang imagined:

> I can picture you in my mind, with your eyes concentrated, hands busy, sometimes you sing … In time, you become motion, you, your experience become living change. (Yang 2010)

Night sky and clock, past and future, cohered in our last meeting. Is the universe one giant clockwork? Jesse pondered the use of gears to represent heavenly motions in the Greek Antikythera mechanism. Jesse's speculations incited Yang to wonder:

> It was not until Jesse talked about it that I started to really see [gears]. I started to see them not only inside of a machine, but also in the sky. The rotating earth becomes a huge gear in the universe. (Yang 2010)

Figure 8. Left: the students' LEGO construction, initially inspired by a toy; Next: revising the mechanism; Middle: adding off-set clock-like hands; Right: The final device.

Having examined at depth diverse instruments of time, the students set out collaboratively, to make one from LEGO. Knowledge flowed through their hands while engaging parts together, critiquing the design, proposing alternatives and rebuilding it anew. One hand-cranked motion transmitted to every other part. Jesse described:

> Using LEGO's to create a gear train (so two hands rotated at different rates on the same "shaft") … showed in a microcosm the complexity of building a working clock. (Thornburg 2010)

Niobium, keenly participating in each observation and construction, was awed by what she achieved together with Jesse and Yang – and might go on to do next!

> I never thought myself talent in understanding something so into engineering. However the outcome was far greater than I imagined—with the help from my peers… As for the mechanism… I did not know if we should try to make an entire clock by ourselves—maybe as big as the Big Ben! (Song 2010)

Those explorations in travelling beyond our time, when undertaken by students through their own curiosity, perseverance, critical reflection, and with companions met along the way, express my hope in teaching.

Conclusion

Gaining an intuitive understanding of time – not surprisingly – takes time. These students took the time to perceive time directly, face counter-intuitive evidence and seek understanding. As the teacher, I suggested ways they might look out from an unexpected tower, wonder about cycles of nature, revisit confusions with machines. Beginning with personal observations of cycles, motions and mechanisms, students experienced these at new depths that, along with exposing what they did not know, also propelled their resourceful investigations.   Had my instructional practice instead "saved time" by resorting to external explanations, it would have shunted out the sturdy ground of learners' observing minds and doubts. Not being in a hurry myself – and not hurrying them to any outcome – I gave them the time to gain their own personal intuition of time and make connections between what they were seeing and ongoing experiences. For my students, this was time well spent.

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[1]Starting in fall 2011, this seminar will bear the course number Edgerton Center EC 050/090.
[2]Unless otherwise noted, all quotes from dialogue in class are excerpted from my assignments, notes and transcripts (Cavicchi 2010b).
[3]The class used the Galileoscope, a low-cost telescope made available for educational uses https://www.galileoscope.org/gs/ The instrument has both a Galilean eyepiece and an inverting 25x eyepiece.
[4]Two web resources for mechanical clocks and supplies are http://www.merritts.com/clock_parts/public/default.aspx and http://www.timesavers.com