Shadows of Light and History in Explorative Teaching and Learning

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Abstract

Shadows are everyday phenomena that intrigued people in the past and remain accessible today. Shadows and history provided the context for lab activities among two teachers who participated with me as learners under the research pedagogy of critical exploration. Eleanor Duckworth developed critical exploration from the clinical interviewing of Jean Piaget and Bärbel Inhelder and classroom practices of the 1960s Elementary Science Study. During critical explorations, learners explore a subject matter without being told what to do or find; the teacher supports these investigations without imposing an expected path. During this study, two teachers explored while looking for each other in a mirror and observing shadows cast by the sun and candles. They responded to historical observations by Ibn al-Haytham, Leonardo da Vinci and Jean Piaget. Together the teachers extended their understandings of light, history and the gymnastic art of following another learner's outlook. In the process, these teachers deepened their capacities for supporting curiosity among the children and students whose learning comes under their care. This example of teaching and learning through critical exploration can empower other teachers to launch students on personal journeys of discovery.

Introduction

To me, teaching is a gymnastic art. A teacher does not simply orchestrate students' learning, but instead, looks for possibilities for students' development by observing how students think and how they could develop. This often requires a gymnastic somersault of the teacher's own preconceptions, which must be turned upside down in order to see the classroom – to the extent that is reasonable – through the students' eyes. By coming to where students are and trying out the mental motions and flexibilities that can be accessed from there, she builds an array of possible further moves and openings both for them and herself. These possibilities become a resource within the teacher's experience, for encouraging students in their own tentative making of leaps, bends and bounds, by which their new expertise and understanding develops.

I seek to develop my teaching in this gymnastic sense. Such teaching requires me to maintain flexibility of response, to notice potential in student work that I did not expect, to adapt class activities in the moment, and give space for student expressions to emerge along multiple ways that may be new to me. By successively studying what goes on as I teach, I extend my range of flexibility and my trust in the diversity and fruitfulness that can come of students' curiosity. In support of my personal efforts to implement teaching as a gymnastic art, I participate in the research pedagogy of 'critical exploration' (Duckworth, 1987/2006c; 1991/2006d; 2005/2006e; 2009a; 2009b; Cavicchi et al., 2009) and contribute the reflective results of my teaching (Cavicchi, 1999; 2005; 2007; 2008a; 2008b; 2009; Cavicchi et al., 2001) toward its development.

Critical exploration, a pedagogy developed by Eleanor Duckworth, originates historically in the clinical interviewing of Jean Piaget (1926/1960) and Bärbel Inhelder (1974) and the classroom activities of the 1960s Elementary Science Study (ESS, 1970). From Piaget and Inhelder, it derives the insight that learners construct knowledge through their directly active engagement with the world combined with their reflective consideration of multiple simultaneous possibilities ensuing from that engagement (Piaget, 1987). The clinical interviewing of Piaget and Inhelder facilitated children in undergoing both active and reflective experiences by participating in provocative activities and talking out their thinking under an open protocol. The ESS program exemplified these qualities in a nonjudgmental science classroom (ESS, 1973). Building on these

examples of research and instruction, critical exploration provides explicit classroom opportunities for active and reflective practices on the part of students and teacher, via an open exchange of perspectives.

In opening a critical exploration, a teacher poses a complex problem or material to students, provides them with direct access to it, and encourages them to explore it through a variety of modalities such as observing, manipulating, changing, or inventing. The teacher might ask questions like: what do you notice, or, what might you try next? To whatever students notice, do or describe, the teacher responds with further activities, queries or materials in an effort to sustain their involvement and expand their awareness of possible ways for exploring. It is crucial that the problem or materials be complex enough to afford students multiple entries. For example, in biology the material might be a sprouting seed (Hughes-McDonnell, 2009), a tree (Julyan, 1988) or live chicken (Rauchwerk, 2005); in literature, a poem (Schneier, 2001); in history, a nineteenth century butter mould (McKinney, 2004); in math, a game involving mathematical operations (Duckworth, 1987). Learners explore this material without being told what to do or find; the teacher supports their investigations without imposing an expected path. Instead of being consumers of facts, learners become observers of the world, initiating personal experiences and ideas that challenge their underlying expectations.

In an undergraduate lab seminar[1] that I teach through critical exploration, students explore materials ranging from everyday items like mirrors (2009a), to lab apparatus like a Bunsen burner flame (2008a), to historical artifacts like an early telephone (2008b). A context of history introduced through readings, artifacts and questions, informs and extends students' curiosity. Students come to personal realizations about historical work and its relation to theirs. They develop into explorers of the natural world and creators of understandings that are open to critical re-evaluation (Cavicchi 2007, 2009a, 2009b). These observations of history in science learning corroborate other studies (Stinner, 1989; Klassen, 2009a; 2009b; Heering, 2000).

Many exercises in critical exploration start with phenomena as seemingly straightforward as light and shadow. Light and shadow are science phenomena that are accessible wherever we are and require no special apparatus: outdoors in the sun; indoors under lights; and at night within what is – in essence –earth's great shadow.[2] Human involvement with light and shadow has a long history where science and art comingle in works of craft, such as sundials, as well as in works of observation, such as drawings with shading. All these features were woven into the experiences of learning that arose during a semester of weekly two-hour sessions involving two participants with myself as their teacher.

Participants Marco and Emanuela, a couple from Milan, Italy, were in the United States for a year of study. Marco, a computer science professor, was doing a postdoctoral research project; Emanuela, a software engineer, was learning English, handicraft arts and other activities. Both had studied college physics in formal settings where opportunities for student investigation were few. During their stay, they became acquainted with such alternative educational practices as the work of Maria Montessori(1909/1964), Reggio Emilia (Cadwell, 1997; Project Zero, 2001), and the MIT Museum's Cambridge Science Festival (2010).

These examples of education through personal experience inspired Marco and Emanuela to ask me to accompany them in their "journey" for realizing that dream for themselves and other learners. Marco wanted to "teach with passion", keeping in mind how new everything is for his university students; Emanuela sought to uncover "the potentialities within the child".[3] This dream of Marco and Emanuela infused our sessions with the work, aspirations, and desire of

teacher education. For us, teacher education meant deepening our explorative relation with the world, and opening it for the learners we will come to teach.

Observing with Light, Shadow, and the Explorations of Another

A core principle of the teacher education that I hoped to facilitate for Marco and Emanuela was the gymnastic art of observing another's thinking and tracing its motions. This activity requires one to develop an eye for predicting where students' thinking might go, and empowering students to go there. Our first activity opened this prospect by putting Marco and Emanuela into roles of observing each other literally in a mirror. I asked them to predict where to place a mirror on a wall that they both faced, so that one could see the other in it. This is a classical exercise in critical exploration that Duckworth (1990) developed in her teaching, which I often introduce to students through contexts with history (Cavicchi, 2007; 2009a; 2009b).

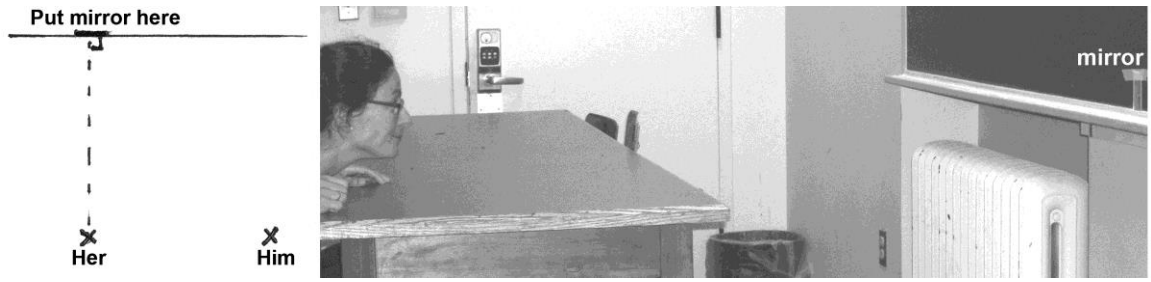

Figure 1. Left: Marco predicts that if Emanuela is in front of the mirror, he will see her while standing to the side. Right: Emanuela looks at the mirror without seeing him.

What surprised Marco most was the failing of his own initial prediction (Figure 1, left). He supposed that with the mirror placed right in front of Emanuela, he would see her in it, while standing off to the side (Figure 1, right). When this was not the case, he moved toward her. Eventually sighting each other in the mirror, "I can see you!", the two contrived to move apart while continuing to hold the other in view by the mirror. Construing how her positions related to Marco and the mirror, Emanuela perceived symmetry in outlook (Figure 2, left). She proposed "you see me when we keep the same angle with respect to the mirror" (Figure 2, middle). They tested this new prediction by moving to many places in the room (Figure 2, right).

Figure 2. Left: Emanuela places the mirror on the blackboard where she drew a symmetry between viewer and object. Middle: She proposes that she and Marco "keep the same angle with respect to the mirror". Right: From far back in the room, they see each other in the mirror.

A key role for me in this journey was to keep their thinking evolving and not dwell on errors. In a successful critical explorations session, errors are enablers of learning, rather than personal failures. Students are encouraged to correct mistakes by direct observation, and to challenge their theories that prove to be observably false.

The mirror activity had Marco and Emanuela acting on the thoughts of each other by putting their whole bodies and the mirror into predicted relations and then extending those through new arrangements. Weeks later at the semester's end, they looked upon this first activity with the mirror as profound. By not behaving as Marco predicted it would work, the mirror revealed how much of the everyday world lay unexamined. For Marco, this revelation deeply unsettled what he thought he knew; he said "I realize that OK, I was not understanding things. I was just seeing things. It was really hard!" For Emanuela, there was the thrill of a world to explore; she reflected: "The mirror is really like putting one foot into a really big land."

Emanuela stepped with both feet into that big land and found herself of accord with others who preceded her. Next time, Marco was away. We discussed our reading of Jean Piaget's (1926/1951) early interviews with children to draw out their ideas about night. The child's view delighted Emanuela by exposing the significance of seemingly "trivial" things. She grasped the integrity underlying a child's reasoning. Restating one child's argument as "night is there because we have to sleep and we sleep well if it is dark", she performed a gymnastic feat of seeing it through an alternative lens, saying "It really makes sense for them, but it is so so funny!" Another child's attribution of life to clouds entranced Emanuela with the child's rationale: "If clouds move, of course they are alive! … movement is attributed to life! I like it!"

Emanuela came to a yet fuller apprehension of the child's view as it welled within her response to a candle she lit. Its flame swayed; Emanuela exclaimed "light that is alive!" Looking at her own reaction with the regard she had earlier applied to child, Emanuela rejoiced "it is so funny! I was like the child! It moves, so it is alive!!"

Playing in shadows, she found much going on. She raised and lowered a pencil; its shadow on the table changed (Figure 3, left). Laying the pencil on white paper, she marked the shadow beneath it (Figure 3, left middle). Raising the pencil toward the flame, she noticed its shadow lengthen and blur (Figure 3, right middle). The shadow's change from sharp to fuzzy intrigued her. I encouraged her to investigate it, saying "there seem to be a lot of things going on." Now she considered other options such as: "move the source of light." Keeping the pencil fixed, she moved the candle toward it and away. As with the mirror, she perceived a relation: among light, object, paper. She reported "I get similar results [sharp shadow] with relative movement: pencil close to paper, or light far from paper."

Figure 3. Left: Moving a pencil near a candle while observing its shadow. Left middle: marking the shadow beneath a pencil. Right middle: The pencil's shadow lengthens as it is raised. Right: a pencil casts no shadow inside a flashlight's beam.

Exchanging a flashlight for the candle, she exclaimed: "O!!! O MY!!" A pencil cast no shadow when it blocked the beam (Figure 3, right). Asking "why is this source of light" so different?, she came back to the mirror she perceived "behind" the flashlight's bulb. I did not point out what is different about the flashlight, but instead looked for how she might observe that difference for

herself. A teacher must be patient and let the student's thinking and exploration take their own path.

Discovery is much more exciting when the student is allowed to take personal ownership of it, rather than being "guided" to an answer. Through being an explorer herself, Emanuela recognized explorative inclinations in others. She told how her young niece collected only the few white shells from a walkway paved in white stones and shells. In the finding of a white shell among many stones -- like with a sharp shadow seen among vague ones – we develop as observers of relation and order in nature.

Observing Light and Shadow from Historical Explorations

Like the child whose curiosity endears us into such leaps of thought as Emanuela experienced in taking on a child's view of night, flame or shells, a historical account can exercise our minds into possibilities that we otherwise may not perform. I encouraged Emanuela and Marco to read investigations of light and shadow by Ibn al-Haytham (1989) and Leonardo da Vinci (1923, 1970, 1977). They gained an appreciative and critical regard of these past works.

Meeting again while Marco was away, Emanuela responded to excerpts from Ibn al-Haytham, an eleventh century mathematician in the Arabic Islamic tradition who innovated an optics based on the eye as a receptor of straight-line light rays reflected from the object, in contrast to the classical explanation of the time, that the eye emits "visual rays". To establish such a profound inversion of the widely accepted "visual rays" involved mental gymnastics. Ibn al-Haytham described his practice as questioning authority and self-critique (Sabra, 2003). His appeal to critique one's own understanding struck Emanuela as a huge challenge:

> The concept [of Ibn al-Haytham] is not to accept passively what we read, but to always question; submit to argument and demonstration. This is really, really tough to apply on yourself! … Don't stop at the first conclusion [that you make.]

Emanuela applied self-questioning when she attempted to redo Ibn al-Haytham's demonstration that light travels in straight lines. He put an empty tube on a straight ruler and sighted an object that lay ahead (Figure 4, left). On covering part of the tube's opening, he did not see part of the object. Emanuela looked through a shiny pipe she taped to a ruler, but on partly blocking the pipe, she still saw the object (Figure 4, middle). Saying "I am not able to reproduce it", she reread his text carefully, inferred a discrepancy in the smaller diameter of our pipe. Again, as a teacher I looked for opportunities to encourage her. Sometimes, a critical explorations teacher may need to wait weeks for an opportunity.

Figure 4. Left: A tube on a ruler between the eye and object; drawing by Cecily Lopes. Middle: Emanuela views the clock through a tube, using a cardboard to partly block it. Right: My sketch of Leonardo's circle where Day [Giorna] is written across its top and Night [Notte] below. The sun is indicated by circles on either side of the diameter.

Weeks later, at Harvard's Houghton rare book library, Marco and Emanuela were awed to turn pages of manuscripts of Islamic science (Vefa undated), the first printing of Ibn al-Haytham's *Optics* (Alhazen, 1572) and a facsimile of Leonardo's *Codice Atlantico* (1973-1975).[4] The mammoth volumes of Leonardo's drawings brought Marco and Emanuela into intimate relation with their extraordinary Italian predecessor. They studied his handwriting intently, silently puzzled. Emanuela walked around the great book, to view it upside-down. Returning to the upright sense, she mused "it is almost like looking in a mirror". Picking up a small mirror – that I provided with this use in mind (but without suggesting that!) – she lay it beside the text. Gradually the inscrutable lettering took on meaning; she exclaimed: "Guarda. Now it makes sense! …We couldn't figure it out. We know Italian. I tried to read it upside down. Our discovery!" That they "took ownership" of discovering the mirror sense of Leonardo's handwriting made it more compelling, than if they were told.

Again the mirror opened a new world for Marco and Emanuela. Leonardo's historical Italian and handwriting proved daunting to interpret. Observing that "even with the mirror it is super-difficult to read", she translated two words in a diagram (Leonardo, 1973-5, vol. VIII, plate 677 back) as *Day* (Giorna) and *Night* (Notte). This diagram depicts a large circle with a horizontal line through it and a small circle at its center (Figure 4, right). *Day* appears above that line, *Night* below. Emanuela executed the gymnastic feat of putting her mind into a pre-Copernican head. Identifying the central circle as Earth, the outer one as the Sun's path, brought her to realize that Leonardo portrayed the sun as going *around* the earth – unlike Galileo!

Historical science widened the community where Marco and Emanuela were exploring. They joined Ibn al Haytham and Leonardo as fellow-collaborators whose studies could be just as puzzling as their own. To actually gain understanding for themselves from these past works involved: looking down real tubes; questioning what was seen; redrawing the sketches of a sublime artist; and restating seemingly archaic words into living languages.

Observing Outdoor Shadows of People, Poles and Posts

Outdoors, light and shadow are in a continual relationship whose changing across a day or a season locally projects motions of the heavenly bodies. Early in our meetings, I asked Marco and Emanuela to notice what they could about sun, sky and moon, and consider what observations they might make that could show something about these motions relative to Earth. These questions lay in the background until we met on the lawn.

Outdoors, Marco had the idea to observe the shadow of his wife. Into her shadow, Marco put a white board, upright. When placed toward or away from her, it showed different parts of her shadow: head, torso, legs (Figure 5, left, left middle). Marco noticed that the length of a body part in her *shadow* varied in relation to her actual body, depending on where it was! He checked this idea by measuring these lengths on her body, and on their shadows (Figure 5, right middle). Her shadow legs were longer than her shadow head. The shadow on the upright board is shorter than same shadow as it falls on ground.

Marco was intrigued. He conceived of measuring that shortened shadow to estimate a building's height: "What about a skyscraper? I am wondering if I can understand the length [of a building] without measuring the entire shadow." As a teacher, I hoped to enable Marco to develop his ideas of proportionality. Marco is highly educated, but that education did not prepare him for this particular kind of independence. Facts were not enough. In critical explorations, students develop skills for approaching the creation of knowledge rather than accept facts.

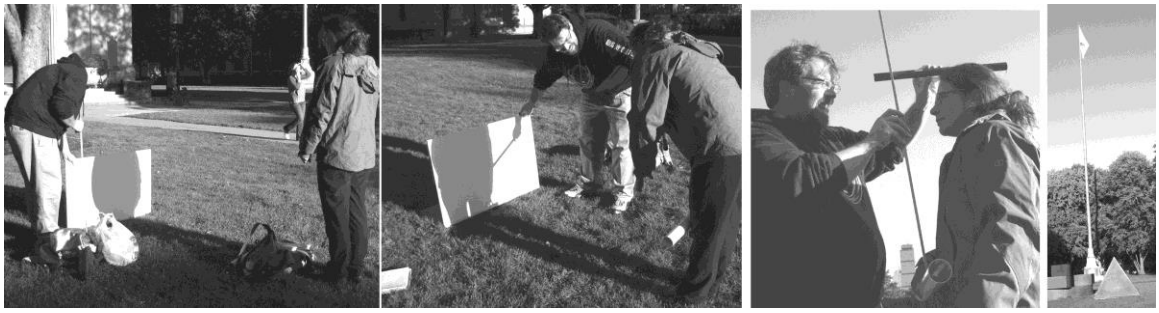

Figure 5. Marco measures the height of the shadow of Emanuela's head [left] and hips [left middle] on a white board before measuring her head's height [right middle]. Right: The flagpole's shadow falls on upright trees.

To encourage their engagement with the flux of our surroundings, I asked "do you have an idea of how the shadow is changing?" Emanuela observed "it is getting longer"; Marco added "and going to the right." I drew their attention to two flagpoles. One flagpole's shadow fell on a tree; Marco regarded that tree's upright reception of the flagpole's shadow (Figure 5, right) as analogous to the white board he held up in Emanuela's shadow! Both flagpoles' shadows were changing too, as Emanuela realized, saying: "Look at the flagpole's shadow! It's longer and longer!"

Pointing out areas on the lawn where the shadow fell and moving his hand to represent the sun, Marco added "the shadow was there (Figure 6, left), now it is there (Figure 6, left middle). The sun is moving in this direction." Emanuela dissented: "the sun is fixed." Now Marco synthesized the shadow's lengthening, noticed by Emanuela, together with its rightward shifting that he identified, into the context of our background question about motions involving sun and earth. Marco said: "the earth is moving [in two senses at once]. Otherwise you are not going to observe only the shadow getting larger but also we will not see the shadow moving from left to right."

We went indoors in a dark lab. Marco proposed using a candle to model the sun with a soda straw as the flagpole (Figure 6, right middle): "This is the same phenomena we were experiencing with the flag outside. The pole shadow is smaller, at base, wider at top; darker inside the shadow, lighter outside." Being struck that so much goes on with shadows, Marco said: "not only the distance, but also the dimension between the source of light and the object, and the distance between the light and the object." Emanuela concurred, "so many variables!!"

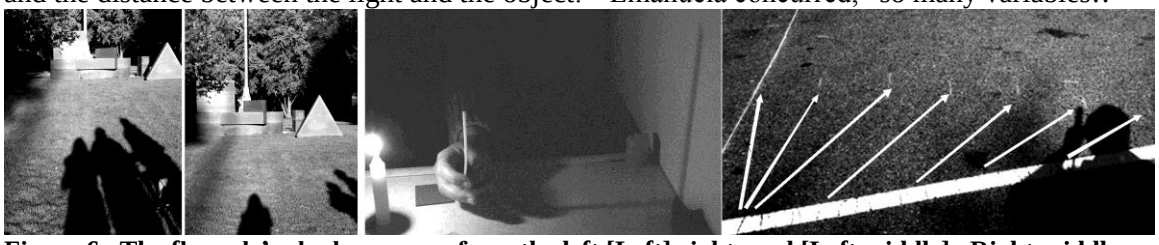

Figure 6. The flagpole's shadow moves from the left [Left] rightward [Left middle]. Right middle: An upright straw casts a shadow like the flagpole's. Right: Added arrows point to marks on the sidewalk at the end of the lamp pole's shadow; it slows slightly in moving rightward; photo by Marco Santambrogio.

In the unreserved questioning that they experienced together, Marco connected to "the unique part of being a child" and voiced the core realization of our shadow explorations:

> [As a child] You are not able to understand; you ask questions because you want to understand. .. adults think they understand, and … are not asking questions. … The important thing is that we are developing our own ideas and that we are intrigued by these ideas and we are trying to explore more. We are pushed to understand the phenomena more because of these ideas. It is not the answer that is the real point; it is the question: are we able to pose questions and investigate or not?

Referring to our background question, Marco reflected on presuming "we know earth moves around sun. This is the right answer." It demanded a gymnastic act of mind to observe without letting that right answer dominate, without letting it shut out new questions.

One morning, Marco and Emanuela mapped the path of shadows cast by the sun. Previously, he observed that when sun shines on a tall pole, its shadow changes more than that of a short one. Acting on that result, Marco compared the shadows of a lamp pole with those of a short tube. Every five minutes, they marked the shadows of pole and tube with sidewalk chalk. Near noon, Marco noticed that successive marks were closer: "it is beginning to get slower" (Figure 6, right). I asked Emanuela what the sun was doing while the shadowed moved as she marked it. She envisioned an inverse relation: "if the shadow is moving this direction, the sun is going in the opposite direction."

The top of the lamp pole's shadow moved more than the tube's. This discrepancy no longer troubled Marco as it had in an earlier session. He related that difference in rate to the mirror activity "Both the [pole and tube] shadow ends are moving … with different speeds. The only difference is the length of the shadow. … The angle is the same … like with the mirror."

The outdoor shadow of a pole is in continual motion, transforming in size and orientation – yet it typically passes unseen. By watching, marking and measuring those shadows, Marco and Emanuela traced out a story of bodies far beyond than themselves, whose relative motions play out during any clear day onto the local surfaces beneath our feet. Seeing those projections for what they tell, puts us into creative activity that respects evidence and infers underlying pattern: following a shadow, coordinating space and time to record its change, inverting the sense of its change to guess the source's path. As Marco realized, all this goes on within an evolving exploratory process that keeps to no script, or sequence of correct steps, or final answer.

Educational Vision and Explorative Practice

Marco and Emanuela came to me with their shared vision of science education emerging through students' curiosity and personal experience. We sought to bring that vision into our own lived experience with our sessions with light and shadows; indoors and out; with historical readings and drawings. Marco and Emanuela exercised their minds flexibly through engaging with the uncertainties of investigating light reflecting off a mirror, deciphering Leonardo's mirror-handwriting and following the sun-cast shadows of poles. The work of that flexibility is evident in the science experimenting generated from their own observations of everyday phenomena and their sensitivity to diverse human responses to science. Having put their vision to work across lab and reflective experiences, the couple contemplated developing it into their future teaching.

An immediate teaching opportunity arose for them with a visit from their school-aged niece. Reflecting on how we had started with a question about earth and sun motion, Marco proposed asking the child what she might do to understand how earth and sun move. When Emanuela feared this opening could be "too challenging", Marco dissented:

> You cannot know if it is not challenging or not. You have to try to put them in that situation. Otherwise they are going to have 33 years [i.e. his age] and someone is going to tell them: "Look at the sky."

Keenly aware of the adult tendency to short-circuit children's explorations by providing 'answers', Emanuela admired Piaget's manner of engaging children through their explorative involvement, such as in recognizing contradictions within their own thinking:

> He [got] them to the point in which they figure out something was wrong in what they were thinking…. the kid would just .. say I don't know. And he didn't say what it was.

During the visit, Emanuela observed herself holding back her adult inclination in order to support her niece's discovery. Later she described a moment where she adopted Piaget's practice:

> [My niece] was walking in the snow. I started to say: "Don't walk in the snow. You will get cold. You will get wet. You will not like it." Then I shut myself up. I said to myself: "Let her experiment. She wanted the snow. Let her find out!!"

On resuming university teaching, Marco seeks to probe and challenge students' understanding. For example, in his classroom of two hundred engineering undergraduates, he posed a competition: to report to him by email any 'errors' they detect in his lectures. By reading and responding to each email individually, he gains insight into students' confusions and understandings. He integrates these insights into future lessons and activities such as viewing science fiction films together. His university teaching thrives on sharing with students the adventure of going into some new area: "What I love is to try new things with the students." Marco shares what powers his vision:

> Engineering students can change the world. Through seeing what can be [as in movies], students can be curious and put their ideas and innovations into action.

This intersecting story of Marco and Emanuela, their niece, his university students, Leonardo, and myself expresses the practice and thinking of putting an educational vision into action. With it, we encourage other teachers, teacher educators, and students that they too can act on personal educational vision, having as resources their own wonder and curiosity for such everyday phenomena as light and shadows. In responding to the unexpected natural effects and seeking to understand the thinking of another – or their own self-critically— they stand to uncover myriad possibilities for exploring and to develop the gymnastic adeptness of mind by which an educational vision becomes a sustaining explorative practice.

In this exercise, two highly educated people put aside the assumptions of their traditional education and became more than consumers of knowledge. They learned to produce facts by observing, hypothesizing, and constructing personalized experiments with sharable outcomes. They also learned how to encourage this kind of development in others. At a time when the world needs true innovators, critical explorations provide a way to incite people to see, create, and evaluate in new and unexpected ways. This is a true benefit of the process of critical exploration.

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[1] The seminar, "Recreate Historical Experiments: Inform the Future from the Past", is an undergraduate elective. Course materials from subsequent semesters are posted on MITOpenCourseWare (2002-2010); under the above title and course numbers SP726 and SP713.

[2] For examples of elementary school curriculum where children explore with outdoor shadows, see (ESS 1965) and (LAPEF n.d.).

[3] All dialogue quotes are from my notes (Cavicchi, 2009c), unless otherwise indicated.

[4] In identifying passages in Leonardo's *Codice Atlantico* (1973-1975), we were assisted by Veltman (1999). See (Leonardo, 2000) for a three-volume edition of *Codice Atlantico*, with Italian transcriptions. Consult (Pedretti, 1978) for cross-referencing between new and old numbering systems.