Discovering Galileo:
Perspectives on learning and teaching through recreating experiments from history

Student Work
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SP. 713
Elizabeth Cavicchi

Acknowledgements

"For to be a teacher does not mean simply to affirm that such a thing is so, or to deliver a lecture, etc. No, to be a teacher in the right sense is to be a learner. Instruction begins when you, the teacher, learn from the learner, put yourself in his place so that you may understand what he understands and in the way he understands it…"

Soren Keirkegaard
The Journals, 1854

To begin with these words is to affirm the process of understanding Galileo through his eyes and experiences. It honors the work we accomplished. Each of us entered into someone else's story, truths became known. Gifts of knowledge offered and received. Thank you Elizabeth, LJ, YY, MC, JF, and DS, Galileo, and Thomas Settle for inviting me into your story. A part of you lives on in my story. I will use the gifts of curiosity, questioning, and courage to view the world through lenses that enlarge.

Introduction

Stories come in bits and pieces. Mine is no different. This paper traces the development of broad ideas about light and optics, discovery and experimentation, and teaching and learning. It is organized into two sections. The first section is a dialog between myself and Galileo. It represents the evolution of my understanding of lenses and depicts a growing relationship between scientists of times past. The second section concludes with a discussion on the teacher-learner-subject matter triad. It is a story that feels incomplete and a bit blurred, much like the looking through a lens – light splitting into rays of colors and merging into diffuse circles. Here I sit, pausing, knowing that at some point in time, I'll understand which way to move the lens, knowing where the point of conjecture exists.

I. A Conversation with Galileo

A Letter of Introduction

January 5, 2010

To the Noble and Most Excellent Signor Galileo Galilei,
TA, student of MIT's most honored scientist and teacher Elizabeth Cavicchi,
sends her greetings from 400 years in the future

Figure 1A Telescope

Signor, I write to you on the 400th anniversary of your first telescopic observations of Jupiter. The world has changed much since your times. We now accept that the earth does revolve around the sun. Our fascination with the heavens persists. People have refined the telescope,

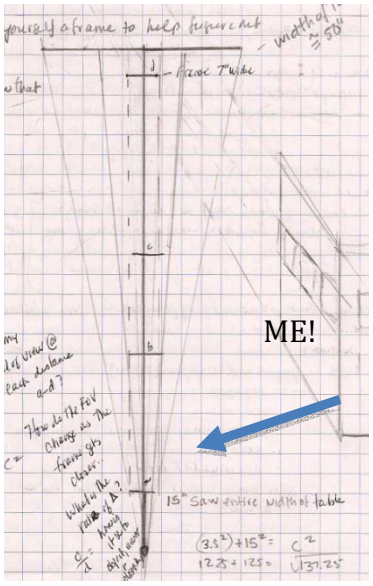
created spaceships and have landed on the moon. Here is a photograph of the surface of the moon. Look closely. Notice that your conclusions that the moon's surface was rough and uneven were indeed accurate!

Figure 2 MIT Place of Learning

But before I ramble on, let me introduce myself. I am a student of your work, studying under the expert tutelage of Ms. Elizabeth Cavicchi with the support of your contemporary, Johannes Kepler, Thomas Settle, who is a modern researcher, and several fellow companions. My companions most remind me of the characters in *Dialogue Concerning the Two Chief World Systems* (2001). Many of them have the wit and perspicacity of Sagredo and Salviati. I, myself, most relate to Simplicio, in that I see, but need evidence to explain and convince. The year is 2010. I live in the fair city of Cambridge, MA, America. The America's, once thought to be discovered by Columbus, are a vast land some 4,000 miles from Padua, Italy. I like you, share a curiosity and wonder about how the world works. First introduced to your work some 10 months ago, while browsing a museum exhibit celebrating your accomplishments, I happened upon your telescope. I expected something elaborate and almost overlooked this long narrow cylindrical tube. 400 year old artifacts are treated with utmost care, and I was not able to hold or use the spy glass. Thus I was left wondering how this unassuming instrument functioned. Since that day, I have desired to build one of my own. During the past thirty days, I have turned my attentions towards the recreation of this instrument.

Alas, making one of my own has not been easy. I turn to you for guidance. The notes in Sidereus Nuncius (Galilei, n.d.) or Starry Messenger as we call it, are cursory at best. My companions, YY (Sagredo) and LJ (Salviati) and I read with ernestness and as you described, determined that we indeed needed two lenses, a plano-convex and a plano-concave, and a long narrow cylindrical tube. Yet we knew not what size these lenses should be nor what distance to place them. Let me share with you our efforts.

Elizabeth, in all of her wisdom, introduced us to perspective. We studied the work of artists of your time – looking for vanishing points and relationships between a frame, a viewer, and the object. I was consumed with determining what effect a frame had on what I could see. I kept my position steady (The dot on the image to the right.). We moved the frame away from me at specified intervals; I recorded the amount of the table, (the object viewed) that I could see. I noticed that as the frame got closer to the table, the table appeared magnified. I could see less of the surroundings and a smaller portion of the object. It seems that the frame focused the view and determined our perspective. We studied your diagram of the telescope.



This diagram seems to be the same diagram that we created over and over again. We have deduced that the tube narrows our field of view, eliminating all unnecessary sights. We also believe that the lenses frame what we see and somehow make the image

appear smaller or larger. But the more we ponder about the placement of the lenses, the more confused we become. You speak of the science of refraction. Would you indulge us and expand upon these ideas?

A Response

April 10, 1630

With respect to a most astute and noble companion, forgive me TA, for I did not trust the strangest news I received on March of this year from a land distant and far. My observations and experiences have not shown me that indulging in teaching across a future time is possible, but then those around me say the earth does not move and I know this to be untrue. Perhaps you could offer me some insight as to how this communication exists?

Now, I presume you are referring to the work in my new book titled Sidereus Nuncius. Here I do describe the workings of the telescope. You ask of the science of refraction. Without drawing this discussion out, I ask that you consider your own ingenuity, for knowledge that derives from your experiences will serve you more than my telling. Have you experimented with the different lenses? Do describe what each does. And as I noted in Sidereus Nuncius, a lead tube and " two glasses, both plane on one side while the other side of one spherically convex and of the other concave (Galileo, n.d., p. 37)" is needed. And now I come to another point and ask how shall you reason upon your conclusions?

With respect to your reference to the heavens and an acknowledgment of my theories, you show me a most incredulous picture of the moon. Tell me about this invention named photograph. And you say that men have walked upon the moon. By what means do they arrive upon this land?

A Discovery of Magnitude

January 13, 2010

To the Noble and Most Excellent Signor Galileo Galilei,
TA, student of MIT's most honored scientist and teacher Elizabeth Cavicchi,
sends worthy news of experiences with lenses

You ask how time and distance are not impediments to our tutelage. Sir, I am not knowledgeable of such matters. I first met you through the written words of Stillman Drake and the spoken language of Elizabeth Cavicchi, a Galileo of our time. And as if magic existed, your very presence was felt deep within. It is only now that I am observing that sharing across time and space is possible. Certainly this is a curious phenomenon of our time. I shall respond to your curiosity of photographs and travel to the moon soon, but with all due respect, I offer you reasoning about lenses.

Figure 3 Lens Experiments

My companions and I have studied these lenses in great depth. A concave sphere seems to frame in such a way that the image appears much smaller and clearer.

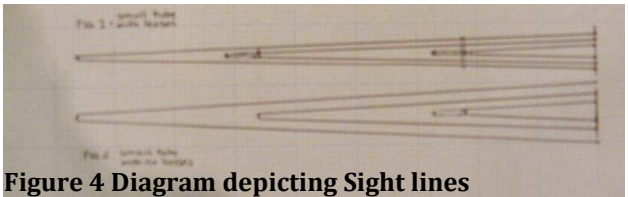
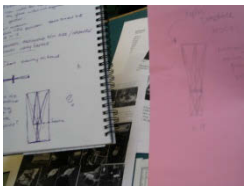


Figure 4 Diagram depicting Sight lines

A convex sphere enlarges. Yan, a pensive experimenter, studied the interaction of these lenses in great depth. Her observations are noteworthy. Movement of a lens away from the eye and towards the object or the other way around, reveals a certain pattern. Somewhere around the point of conjecture, the lens seems to pass through a state of confusion. The outside edges spread the light into multiple colors. Fuzziness progresses toward the center. A pattern that reminds me of the eyes of cecropia moth presents itself. (Have you noticed these moths in Padua?) The eyes expand into concentric circles until the image reappears only upside down or right side up (which ever is the opposite of its start.) I wonder if this fuzziness is the point at which all of the light rays are nearing their point of conjecture? No doubt that you might have had some experience with this. Ah, and yes, we did experiment with pairing of lenses. Of particular interest was the pairing that you mention in the Sidereus Nuncius (Galilei, n.d.) When used in combination, we surmise that the concave lens shrinks the image and at the same time makes the details more clear. The convex lens expands the shrunken image, giving the appearance of a magnified object. We see a smaller portion of the object in much greater detail. Our diagram looks very similar to yours. But why does this happen? How is the light traveling through these lenses and what does the lens do to the light? I know not how to answer this question.



Oh… Signor, have you met Johannes Kepler? It was our luck to have encountered him, well his writing anyway. He has some ideas about how light interacts with lenses. We are intrigued. Leigh has drawn diagrams similar to his, but his ideas have not taken hold in our minds. Light is elusive!

Figure 5 Leigh and Kepler's Work

And dear sir, we have fashioned two spyglasses. One is 6 inches in length and magnifies a bit. The other is 10 inches in length. We can see some 50 feet a way. What proof do you have that the telescope you describe is of value for seeing great distances?

Oh, forgive my ramblings. Time travel has proved to be less of an impetus and more of an impediment. I feel obliged to impart much of our curiosities. My companions have studied light using a light machine and spherical lenses. These diagrams (NN, 1/27/2010) show how the spheres bend the light.

Figures removed due to copyright restrictions

Trial and error… questions and curiosities, we came to some propositions, that perhaps your telescope was able to magnify because “a concave lens by itself makes light rays go away from each other and a convex lens makes them

come together so it makes sense that putting a concave lens next to a convex lens straightens things out again! (SS)" and of course, makes the distant image appear larger.

Lenses continue to confound. Dear Signor, how is that when you view through a concave-convex lens the image appears to remain the same? That is what we see. I am gathering proof that what we see and what really exists is not the same. I devised a measuring tool – cross hairs placed on both the lens and the case. Fixing the distance from my eye to the lens to the eyeglass case, I lined up the two cross hairs. I measured how much of the eyeglass case I could see. Surprisingly, when viewing from concave to convex the eyeglass case appeared larger; in reverse, viewing from convex to concave, the eyeglass case appeared smaller and lower in the lens. Tell me most noble learned one, what is your experience?

October 15, 1630

My learned pupil, it seems that you and your companions have progressed in your learnings. And ingenious propositions have been proposed. It saddens me to inform you that Signor Kepler has left this world for a place that souls retire to after a life of work. I do admit that while Kepler has pursued me, his writings have not aroused an interest in me. I see from the geometrics that he is deciphering the very same relationships that I know from experience. I busy myself with starry nights and lunar sightings and my writings. Tell me of your experiences. Do you hold the idea that the moon is smooth and spherical? How do you shape your lenses? How has my work in the Assayer been received?

January 23, 2010

To the most Noble Viewer of the Heavens Galileo Galilei
TA, companion and experimental researcher
Sends word of great discoveries

What a miraculous night! Our learned professor procured a celestron telescope. It is much larger and more complicated than the instrument you are using. The parts are many and finding Jupiter and the moon challenged all of our sensibilities. Our eyes were not well adjusted to an upside down image nor were our fingers nimble enough to bring the heavens into view as quickly as they moved.

Oh, my friend Galileo, I witnessed the moon in all of her glory. With my eyes transfixed, I soaked in the rough, uneven features – craters, mountain ridges separated by stretches of valleys. No, the moon's surface is not even and polished as I have witnessed for many years. It is indeed as you described "uneven, rough, and crowded with depression and bulges (Galilei, n.d., p. 40). And the separation of dark from light – with a half-century of experience, this separation has always appeared even, unlike your description of an "uneven, rough, and very sinuous line (Galilei, p. 40)" And tonight, the moon convinced me that you, heavenly explorer, had seen and described. Confused by your passage describing the movement of light across the moon's surface, I could not believe; I had no evidence. But alas my eyes have witnessed something

every so glorious. As I was watching the moon, a lunar spot, as you describe, was in shadow. In a flash a bright white light crept over the spot illuminating its brilliance. Dark and light danced. The moon is new to me; with my unaided eyes I see it differently. In my journal I write … *I gazed up and there, perched atop a steeple, was a brilliant white globe. The sight took my breath away. As I gazed at the dark shadows, Galileo's descriptions of the moon danced in my head. My observation of a crater engulfed in shadow and then suddenly illuminated with a bright light entered into the picture. Tonight, as I gaze at the moon, I feel a kindred spirit with Galileo and all those who have puzzled and marveled over this miraculous sight.*

Kindred spirit…I realize that as I recreate and immerse myself in your world, I see another perspective. My listening to and honoring you has stirred within me deep curiosity, wonder, and awe, for you challenged authority, trusted your observations, and worked diligently. Experimenter and researcher you are. I am honored to have walked alongside you these past thirty days.

March 1633

My dearest friend and learned student
Galileo, broken and ill
Sends word of trials and woes

My beloved friend…I know not how this communication has been possible, but am grateful for words of hope. For me the times are difficult at best. My life's work is under siege, my health is declining, and an interrogation by the Inquisition is upon me. Your due diligence to experimentation and writing inspire. I trust that you have come to understand that your ingenuity and knowledge wells up from within, that raising questions and observing closely is a source of discovery, and that the natural world offers many answers for those who dig beneath what is seen or told.

I share with you a piece of my last writing…know that I remain committed to the spirit of challenging what I know not to be true, but I am an old man and must survive.

> ….I have been judged vehemently suspected of heresy, that is, of having held and believed that the Sun is the center of the world and immovable, and the Earth is not the center and moves. […] I, Galileo Galilei, have abjured as above, with my own hand (Sobel, 2000, p. 277)

Great comfort shall come from future words of you.

February 1, 2010

My beloved friend, Galileo
TA, an aspiring Galilean
Sends words of comfort

A heavy heart ladens my last words. I can only imagine the weight that rests upon you, charged with heresy, viewed as a renegade, in receipt of little support for your propositions and theories. You set the world in motion and forged a path for future scientists to inquire and refine. I share with you the words of my most honorable and humble professor, Elizabeth Cavicchi (personal communication, 1/31/2010). May you find comfort and peace.

> The college students who participated in your explorations this month extending those with their own insights and discoveries, give a wonderful tribute to the possibilities for learning that you opened for all of us, 400 years ago. We have much to learn from them too, now and in the future of their own expression of your exploratory example.

II. Learning and Teaching

I enrolled in this course to understand what it meant to be a learner immersed in an unfamiliar subject matter and to unpack the process of constructing knowledge. What experiences supported or thwarted my learning? What engaged and motivated me? What fostered the synthesis of my ideas? Did I actually learn? In what ways would the experience inform my teaching? In so many ways, it is a challenge for me to boil down my learning into a few main points. The process has been complex, non-linear, and brimming with connections and enlarging perspectives. Perhaps the best approach would be to discuss each element of the teacher-learner-subject matter triad individually, follow this with a look at the interdependency of each, and conclude with a commentary of implications for practice.

Infusing and extending subject matter through history and experimentation

Thomas Settle (1996) writes "If we are to understand Galileo's own words and diagrams, we should try to learn how the physical world presented itself to him (p.6)." I did not fully comprehend the intent of this statement until the last day of class. I knew that Galileo had developed a telescope, had lent support to Copernicus's theory that the earth revolves around the sun, and had spent the last part of his life under house arrest for going against teachings of the Catholic church. Beyond that, what else would I really need to understand? How naïve I was!

Galileo, first introduced to us, as a biographical timeline, seemed to be quite an accomplished individual with an interest in astronomy and motion, a flair for writing, and quite controversial for his time. Like any other relationship, as we interacted with Galileo through his writings and experiments, read criticisms and interpretations of his work, and explored the context of his life, Galileo became known to us as a skilled artist, an accomplished musician, an astute mathematician, and a researcher. He questioned authority, trusted his observations, pursued his questions, and investigated many aspects of the same idea until he had sufficient empirical evidence to support his theory. He was a renegade scientist of his time.

What made this revelation possible? Much like Galileo's own interest in exploring aspects of the same concept in varied contexts, we interacted with content through a variety of materials, readings, and experiences. Frames, mirrors, lenses, light and inclined planes, balls, and weights, always available and forever complex. Sometimes we came with our questions ---

"What does a concave or convex lens do?" "Hmm, that's surprising. What makes it float?" Other times, we poured over Galileo's work and used his ideas as a springboard for investigation. Yan would read, gather pendulum equipment and recreate Galileo's experiments. She tried out the horseman experiment, throwing a ball upward while running forward. Where would the ball land? Could she catch it? LJ and TA worked to understand how Galileo built his telescope. MC studied motion, testing Galileo's assertions and trying out her own. Somewhere along the line Galileo's story as researcher and ours as experimenters intersected. The obvious was no longer obvious. What we thought we knew, was no longer true. The materials demanded that we dig deeper. Their secrets only unfolding after connections between readings, experiences, and experimenting were made. This was borne out when TA, after weeks of working with the optics of lenses and searching for an answer to why does concave-convex lens shrink the image in the same way no matter which side you view the image through came to the conclusion that Galileo did not have to understand the science of refraction. His manipulation of combination of lenses and his use of geometry helped him understand the relationship between the viewer, the frame, and the object. In the case of investigating the splitting of light, LJ, JF, and DS were left puzzled. DS writes

> […] "Look at the blue light over here." I looked at where she pointed, and sure enough, there was a blue ray of light emanating from one of the lenses. I was completely dumbfounded at this point. This was so incredibly exciting because I was witness to some miracle of nature, brought into being by this machine of these three experimenters, that was creating behavior I absolutely could not justify. There was not blue acrylic on the light ray slot, only red. And yet somehow and entirely different color of light, appearing seemingly out of nowhere, presented itself to us. This was one of the great moments of the day—a beautiful, unusual observation, and I had absolutely no justification for what was happening. And that was okay.

We experienced content through immersion into the time period. Entering into the reading room in Houghton Library evoked a sense of awe and reverence. As we poured over 16th century books, diagrams that we drew were found in Kepler's work. How amazing is that? Kepler actually did the same kind of work as us (or perhaps it is the other way around.) A visit to an exhibit of historical instruments yielded even more knowledge. When comparing the various measuring tools with Galileo's military and geometric compass, you could see how his instrument built upon existing tools. A collection of telescopes demonstrated how the instrument changed over time. And an unusual instrument used to measure the angle of incidence added just a bit more information to the ever widening puzzle of how does one observe how light passes through lenses. Last, observing the time honored tradition of glass blowing using techniques developed 400 years ago, provided a window into the complexity of making quality lenses and added to our growing understanding that Galileo has success in part due to his ability to procure higher quality lenses.

Unlike our traditional way of teaching, where students encounter content from one point of view and from one authoritative source, situating content in the context of a time and place and exploring the subject matter in all of its complexity enriches and enlarges. I write (TA, 2010):

> YY raised the issue of complexity – didn't Eleanor talk about how important it was to be immersed in the complexity of the subject. It is this complexity that offers possibilities and keeps us engaged. Yes, this is a great point. Galileo is complex. In this complexity, there is a richness. I see that I can explore the science, the person, and the history. I also see that dissecting each piece without considering the other tells only part of the story. Great subject matter has many facets. To simplify the story would reduce it to facts and bits and pieces of knowledge.

Infusing our studies with history and recreating experiments opens possibilities to dig deep, to go beyond, and to construct knowledge that becomes part of ourselves and our history.

A learner's perspective about developing understanding and experience

Early on in our readings of Galileo, I began to envision him as individual open to possibility; someone who trusted observations; a thinker who challenged current understandings. Drake (n.d.) writes about Galileo's penchant for observing over explanation.

> […] inherent capacity to observe that modern science owes its inception; for despite his extraordinary capacity for reasoning […] he turned away from excessive speculation about causes of things. His desire was to see precisely what things happen and how they happen, rather than explain why they happen (p. 69)

Galileo (2001) continued to share glimpses of his perspectives of the dispositions necessary for learning. He writes

> Simp. I should say in the first place that I have not observed any such things; second, that I do not believe them; and then, in the third place, if you should assure me of them and show me proofs of them, that you would be a veritable demon.
> Sagr. […] But the showing depends upon you that if one does not know the truth by himself, it is impossible for anyone to make him know it. I can indeed point out things to you, things neither true nor false; but as for the true—that is, the necessary; that which cannot possibly be otherwise—every man of ordinary intelligence either knows this by himself or it is impossible for him, ever to know it (p. 183).
> Simp.[…] allow me to tell you that I neither know nor understand the things in question. Therefore see if you can satisfy me as to these problems.
> Sagr. Now as to the reason for that, Simplicio, can't you make up your own mind about it without somebody else teaching it to you? (p. 183).
> Sagr. You have seen right through it for yourself, by your own ingenuity. [….]
> Salv. I am pleased to see Simplicio's exercising himself—if indeed the ideas is his, and he has not borrowed it from a certain handbook of conclusions in which there are others no less elegant and ingenious. (p. 202)

What I take away from this is that observation serves as a foundation for wondering, experimentation, and coming to understand. It is an essential component of learning. In addition a learner must question, must experience, and while book knowledge is a source of knowing,

understanding only comes from deep within ourselves. The learner is the author of his or her knowledge.

Over and over again, I witnessed these aspects of learning. MC articulated her perception of observing, stating

> I begin to appreciate all the small things that happen around me. […] I see the instruments [in the gallery]. I start to think "what is the use of that instrument and how [*does*] it function? I try to think: mirror; I try to relate them together, how it works. […] I treasure my life to observe (Cavicchi, 2010).

LJ was persistent in her questioning, pushing all of us to dig deeper. She really sat with the materials, testing idea after idea until finally something clicked. At this point she recorded her thoughts. YY pensive, tried out an idea and returned to thinking. She questioned what we saw; pushed us to explain our understandings; found the inconsistencies in our arguments and often referred us back to Galileo's suppositions. JF proposed ideas, manipulated materials, and articulated what she saw. MC played with materials, observing properties, formulating questions, testing ideas across different mediums. She wrote; she reflected. Her documentation showed her the process. I questioned, and explored concepts in a various ways. Much of my time was trying to decipher how all of the different pieces connected. Going from whole to part and back to whole brought clarity. DS proposed explanations. He puzzled over the why. After his experience as teacher-researcher he commented " I moved forward promising to observe more, judge less, and experience the natural world and the things in it for what they are (SS). All of us saw our ideas as improvable. We investigated and revised. We learned from our experiences and those who came before us. I am not sure if any of us left feeling convinced of our knowledge, but there is still much more time to explore.

What I take from all of this is that learning is personal. We each have our style, our approach, our questions. Observations, especially those that are counter intuitive propel us forward. Learning is fluid – we move from one activity to the next, depending upon interest, connection with the current experiment, or need to pursue another line of thought. Learning is non-linear. We move from not knowing to knowing and somewhere in between many, many times over a course of hours, days, and weeks. An activity that seems so disconnected from a line of thought, actually may be the key. Our collaborations through writing, speaking, and doing challenge and push our construction of knowledge. We each take in what we are ready to hear and assimilate. Our reflections on our learning allow us to sift and sort, to articulate what is clear or confusing, to mull over points. Looking at learning through multiple lenses enhances and enlarges perspective. And of course, the perspective is very dependent upon the viewer, the frame, and the object.

I end with something I take from Thomas Settle (1962). His exploration into Galileo as a learner moved me. Galileo was curious. He felt a need to make sense of his observations. Answers or connections only came after years of trial and error. He used what he knew in one area to make sense of something else. Galileo was quite comfortable sitting in what Settle coins the phase of discovery. Over the past 4 weeks, I have experienced this phase of discovery. We

lived it. We had hunches, we sat smack in the middle of the messiness of learning, we experienced ambiguity and confusion, we discovered our capacity to think, to create, and to make meaning for ourselves. Paraphrasing Sagredo (Galilei, 2001, p. 183). We saw through it for ourselves, by our own ingenuity. [….] and Galileo would have been pleased that we exercised our ideas!

Teaching and the "over repeating story"

> Salv. What we are here for is to discuss things, and it is good for everyone to raise his objections as they occur to him, for that is the road to knowledge (Galilie, 2001, p. 179).

The over repeating story begins with the teacher. As I read Galileo's *Dialogue Concerning the Two Chief World Systems,* I immersed myself in an exploration of ideas, justifications, and possible theories. I witnessed a teacher and two students conversing, experimenting, pushing each other to go beyond. And 400 years later, for thirty days, a teacher and 7 students conversed, experimented, and pushed each other forward in their thinking. We identified with Simplicio, Sagredo, Salviati and Thomas Settle. We met glassblowers of our time who did the work of Galileo's time. We read books of the Galileo's time and saw the work of our time in these books. We built the tools of the time and compared them with the tools of our time. We experienced similar confusions and revelations. We recreated similar experiments and drew the same types of diagrams and the same kinds of conclusions. How could this come to be?

In many ways it was Elizabeth's dedication to and deep understanding of Galileo and her commitment to situate us in the midst of a complex subject matter that started our journey. In many ways it was Elizabeth's ability to relinquish control of what to learn, how to learn, and when to learn that allowed us to raise our questions, to set a pace for our learning. In many ways it was Elizabeth's modeling of how to sit with confusion and to marvel at wonder that allowed us to see ourselves as observers, thinkers and makers of meaning. In many ways it was Elizabeth's belief and trust in the process of learning that supported our willingness to share vulnerabilities and insights. In many ways it was Elizabeth's ability to put herself in the role as learner that modeled for us ways of learning. Together we relived the world through Galileo's eyes.

A teacher sets the environment and invites you in. From here on in, the teacher listens, asks the just right question or provides the just right materials that support the next investigation or line of thought. The teacher crafts the experience that encourages student thinking to be made visible. The teacher observes a story unfolding, moves in and out of the collective story, and delights in the successes and supports in the midst of our struggles. But who is the teacher?

Intersections…

As I sit, I think of the complexity of the teacher-learner-subject matter triad. For all of this learning to work, there is a give and take between each part. At some point, each of these constituents changes its role, shows another facet, and becomes a teacher. Learning is more powerful when we abide in the messiness of learning, when we situate the learning in the context of time and place, when we open our hearts and minds to perspectives that enlarge. Elizabeth

(personal communication, January 21, 2010) words to Galileo, best summarize the intersection of learning and teaching:

> Your story is within all of our stories, and gives each of us personal openings, through yours, to discover the behaviors of nature, the delight of exploring, the struggle of being in uncertainty and controversy - by the profound depth of each of our ways of experiencing the world.

Implications for my teaching

Let me revisit this idea expressed by Settle, "If we are to understand Galileo's own words and diagrams, we should try to learn how the physical world presented itself to him (p.6)." Yes, after weeks of trying to make sense of the science of optics, I realized that Galileo did not need to know this bit of information to build his telescope. In fact, it wasn't until the 11th class, when I played with the lenses, testing out my hunch that I came to the realization that if I used geometry to understand the relationship between the frame, viewer, and the object, I would know which lenses to use and at what distance to place them. The idea of similar triangles that emerged on day one and repeatedly emerged in many different venues finally made sense. Galileo knew how lenses changed the image. He knew which combinations of lenses achieved what results. He understood the relationship between the viewer, the frame, and the object. Everything about him led him to feel confident in his knowledge and allowed him to create.

How powerful a revelation! This came about because science was not reduced to one idea, but experienced in a time and place and through many perspectives. As I return to teaching, this is the gift I wish to offer my students. Perspectives, emerging questions, moments of wonder, answers, and just as we come to understand, we realize there is more that we do not comprehend. As Simplicio remarks, "I am good evidence myself; for the farther on this goes, the more confused I become (Galilei, p. 150). We end not on the finality of a right answer, but on the horizon of new questions, poised for the next exploration. "Now, what would Simplicio say to that? (p. 183)"

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