My Story of Encountering Galileo

Grown up in a rural village, where people lived on what they grown in the field, produced stuff by hand, consumed goods that they required for basic living, I always feel cities strange. For instance, like the library I am studying in, it has even and well-arranged light, ventilator on the smooth ceiling, luxurious chairs, clean and tall windows, dustless wall, and rows of bookshelves carrying uniformly bound files and texts. In daily life the things that I use, like the computer, the watch, plug, and adapter, they are strange as well. In my hometown, I saw familiar people working together to make a house, I saw the bricks being laid day by day. In cities, however, buildings under construction are usually covered by some thing, and a period of time later they appear as finished, tall, new and modern.

There seems to be an ode to science, technology and modern civilization that contribute to the convenient and comfortable living I am leading. They have power dominating, shaping and creating our life. They are strange, mysterious, and dauntingly potent. After near a decade of experience navigating in cities, I take it for granted to co-exist with the strange.

My experience encountering Galileo in SP 173 brings a sense of familiarity for me with science. The very sense of familiarity leads me to reflect upon what was previously taken for granted, not only the physical phenomenon that we studied during class, but also the nature of science and history, as well as the nature of teaching and learning.

Experiments and experience

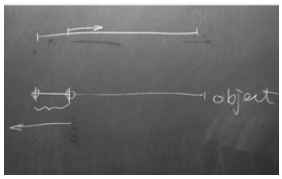
Just as Galileo's explorations, my experiments and experiences were related to each other, and I realized that the more I think about what I did, the more connections and questions emerge. It is also remarkable to realize that what I did was always in some way tied to others' experiments and experience. The "others" could be my classmates, figures in history, my teacher, or Galileo. In the following part, I will retell the story of my experiments and experience in combination of PowerPoint slides; moreover, I seek to grasp the chain of evolvement, to understand how my curiosity was ignited and sustained, how connections were possible and important.

Frames and mirrors

We played with frames in the corridors, read illustrations of people drawing, looked through tubes outside, played with lots of different lenses and mirrors, read historical stories about spectacles, telescopes, and books that Galileo wrote, and tried to build our own spyglass. At the beginning of my exploration together with my classmates, especially when we were playing with frames, I was surprised sometimes by our discoveries, but easily found everything reasonable and didn't feel much confused and interested. Later on, when each of us shared what we discovered, when I saw the lute that my classmates were drawing, when I caught up the readings, I felt that I

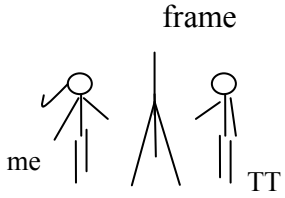
constantly formed new ideas to be test out and eager to share with others what I found, moreover, my prior experience and judgment were undergoing examination as my thinking and understanding evolved.

During the first class, I found one phenomena surprising: if the viewer and the frame move at the same pace along the line away from the object, the frame image would appear the same. (Class Summery, Cavicchi, 01.04)

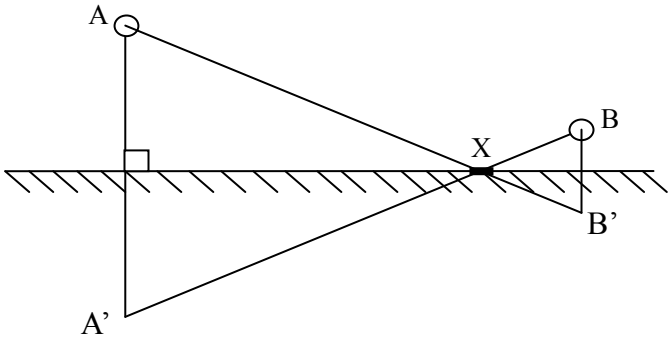


After reporting this observation to our class, I felt it quite surprising but was not quite much interested in learning more about this. Some time later when I reviewed the diagram that I drew on the blackboard I found my discovery questionable. It didn't make sense. If the frame and the viewer move further away from the object, the object should appear proportionately smaller. This apparent effect was not obvious to me at the beginning, but later when I had more experience drawing other diagrams and doing relevant activities.

The other phenomenon that I noticed was shown in a diagram below.

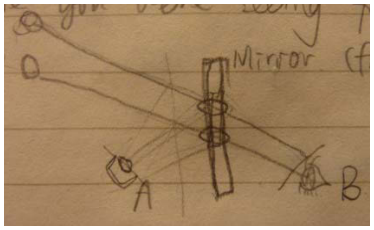


If TT and I kept moving toward each side at the same pace, we would appear proportionately the same size in reference to the frame. This reminded me of a diagram that I drew in a high school class. This diagram was recollected earlier in another class. X is the place a mirror so that A and B could see each other from the mirror.



A' was viewed as virtual image to A, which was the same distant to the wall as A. My problem was I couldn't understand what was A'. I could not understand that diagram and it kept me thinking. When part of our experiment with frame was similar to this diagram, it quickly propped into my mind. So I was wondering what if I

replace the frame with a mirror. For sure I would not be able to see TT, what can I see? I would be able to see what TT could see if the mirror was still a frame, which was myself! If I was not facing directly to the mirror, previously the frame, then what could I see? What I could see through the mirror should be the same thing that TT could see through the frame. Look at the following picture, suppose A is me, B is TT, in the middle is a place to locate the mirror or frame, on the left above level is the object.



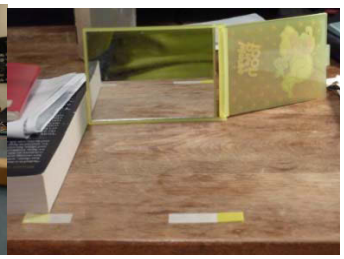
If there is a frame, B could see objects through the frame; if there is a mirror, A could see objects reflected through the mirror. Both images should appear the same to both people, except that the mirror image is flipped over from left to right.

Later I did experiments with a camera to capture images at two viewer points. The left image is reflected from a mirror, while the right one is seen through a frame.

Although it was not very a precise experiment, it confirmed my understanding of the diagram. And it was exciting to test it out in real life.

This experience gave me a sense of what happened inside of the mirror, which deepened my understanding of A' in the diagram.

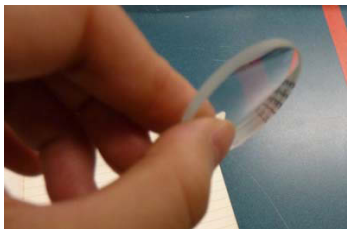
Daily observations with the mirror also propel me to think about vanishing point in a mirror image. Why objects were seen as significantly smaller in the mirror, as if the image of objects travelled a long way to reach the viewer's eye?



Lenses and telescopes

Lenses were interesting to play with. By simply looking through a piece of lens, a lot could be found. The first realization that I had was my long-term confusion about the

half-rings inside glasses. I don't wear glasses myself. I noticed that people's glasses have several half-sized rings alongside the edge; I thought it might have something to do with the degree of myopia, always wondering if inside of a piece of glass there were some half circles inherent in it. By looking at one piece of lens, I realized that my previous thought was quite wrong.



In this piece of glass, with some black characters at the edge, I saw the half-rings as well as its black characters. So it was clearly not inherent inside of the glass, rather it was something going on. But how could that happen? I am still quite confused. Is it because that one side of the lens' edge reflects the other side of the lens' edge?

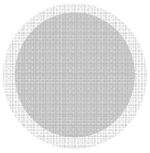
Be exposed to many pairs of glasses, I was very excited to see their diversity. I touched them, wore them and came up with the idea to line them up according to their thickness in the middle or rim of the glass. It was very surprising to see through two pairs of glasses if one of them is thicker in the edge while the other is thicker in the middle. As a people with normal vision, I felt comfortable to see through a pair of glasses to be normal and the image was quite normal as if I didn't wear them. After class, I told my husband about my discovery, he told me that if the two pairs of glasses were put some distant to each other, they could form a simple telescope. I was very surprised and wanted very much to try it out myself. Next class, I tried to put the two single pieces of convex and concave lenses in a line and see what could happen. Later when I read the articles about the invention of spectacles and telescopes, I was amazed by how those could be related to my explorations. The personal communications and historical article reading gave me a strong sense of dialogue, a strong desire to test it out myself and to extend my previous exploration.

Having a lot of lenses and glasses at our disposal, I felt reluctant to explore them all at a time, rather I felt more comfortable to play with just one piece of them. When I held a convex lens to see the spectacle case in front of me, I first wanted to see how much the case could be magnified by the lens. To my surprise, if my eyes and the case stayed not moving, while I pulled the lens back and forth, the image through the lens changed dramatically. When the lens was very near the case, it magnified, then when I pulled the lens back toward me, the image got more and more blurred until at some point it was totally a mess, and then, the image would be turned up-side-down. LL was surprised when I told her what I found, which made me very happy. MN, however, didn't seem surprised because she discovered that effect earlier. At that time, I thought, hey, how come she didn't share her discoveries when she made that discovery? It was worth cheering and sharing! With other convex lenses nearby, I tried to put another piece right next to the former one, and wanted to see the

difference. I found the lens with greater curvature would magnify greatly and the image flipped over when the lens was very near the case, while the lens with weaker curvature and the image flipped over when the lens was a little further away from the case.

I continued to play with them roughly two weeks later because I still found the sequence of changes amazing. This time I observed very closely. TT joined me which made me very excited. She was very intrigued by the changes and the spectrum around the edges when the image got blurred. The question for me was why at one point the image will flip over? Does it have something to do with focal point? How to find the focal point? What is a focal point?

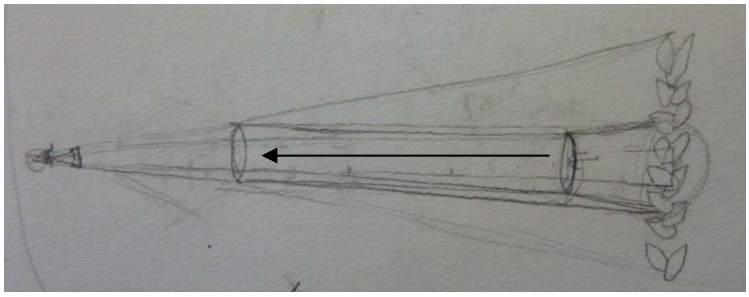
As all these questions remain unanswered, I got some insight from MC while she was using a torch to illuminate three lenses. When we turned the light off and the torch on, what I saw was stunning. Though I forgot the details of the experiments, I remembered that the image projected onto the dark paper got sharp and light seemed to converge at some point; the image projected into the black paper became sharper while other time they were diffuse. This directly led me to have my experiments in my room. TT was more than happy to join me. It was very simple experiments: to find when the light converges for a convex lens and for a concave one. While for convex lens, light did converge at some point; for concave one, there was no such an effect. It had a darker round plane inside and a lighter ring around the round plane.



While those effects were impressive, I felt I didn't understand them. I felt I couldn't tell why they looked like that and I wanted to go beyond the effects to know more about how these effects were created. But I felt that I had a deeper understanding of vanishing point of convex lens and the perspective exploration I did in Library. I realized that the torch needed to be held a certain distance away from the convex to create a converged point on the targeted black paper. Was that because that the light beams should be parallel so that they can come to one point at the other side? This is so similar to the discoveries I found through perspective observations. The vanishing point actually is where the parallel lines extend and meet each other and specifically those lines that are perpendicular to the viewer's perspective. Unparallel light beams might travel through the lens and converge to create a converging point, just as radiant

shape could be seen as having a vanishing point from our perspective.

That night, after this experiment, TT seemed to have some new ideas about how a telescope worked. She was drawing a diagram to illustrate. I didn't understand her diagram. Maybe partly it was because of language sometimes I couldn't understand my classmates' conversations. Maybe I should have been more patient and open to listen to her explanation. Instead of listening to her explanation, I told her I was thinking about a different way to draw this illustration and would show her when I finished drawing. I haven't finished yet. It was too complicated. But I showed the early draft to Elizabeth, and she seemed really interested in my drawing. It was an effort to combine my experience with frame activities to understand how things were magnified through a telescope.



In our group work, we noticed that given the viewer point and object, if we move the frame further from the viewer and closer to the object, the object captured by the frame appear to be bigger proportionately. We tried to draw what was seen through the frame. The viewer walked toward the frame, picked up her pencil and paper, looked at the frame again, and realized, ha, what she could see now was totally different from what she could see before. So I was wondering when we proceeded to play with lenses, the effect of lens, or the magnifying effect was actually to pull the scene in the frame from a further distance to a closer distance to the viewer without losing the proportion of image to the frame.

This, of course, is an incomplete explanation. It is an effort to bridge what I know about the telescope and what I experienced myself in frame activities. It didn't explain actually, even how the convex lens works. Now when I am thinking about the convex lens and spectacle case activity, I feel this illustration can't explain that close magnifying effect very well. Since, if I put the lens at the surface of the spectacle case, the image of the case is quite as normally seen without the lens. But if I pull the lens toward me, the image inside the lens is part of what was seen when the lens was stick to the surface. Where have those parts around the edge gone? Interesting! It seems that the lens collects a smaller area of light at one side, and then spreads that group of light to a larger area at the other side. But when it comes to a light source that is very distant from the lens, it seems that the lens collects larger area of light at one side and then converge the light at the other side. Moreover, how could this relates to my observation of convex surfaces of objects, like the wallet, and the cookie can? Or are they related?

Maybe they are not. The only similarity between the convex lens and the round can and curve wallet is that they have a convex curvature. This might be a total different case. They are just receiving light from a light source, like lamp, and reflecting the light to a certain direction. They are more similar to convex mirror. Still, there is something to do with the convex curvature; so I am wondering if there is something could be known to explain both cases.

Back to the lute drawing

As mentioned before, there were a lot of cases that my experience of later and that of earlier merged. The combinations emerged unconsciously and unexpectedly. When I was re-reading my notes early in the beginning of our class, I remembered the confusion that I had when seeing my classmates' work drawing a lute. I didn't know how they made it. They didn't know either. I was confused, I persisted at figuring it out for a couple of days, but let it go as time went by. Recently, when I was reviewing my notes, I came to understand how it worked. I think it was owing to my experience playing with compass and understanding magnifying and shrinking effect of lenses. It was incredible joyful to clear up one's own confusion. I also come to see that it is hard, even impossible, for the teacher to decide when the student should and could come to a transformative point. It was quite unexpected for both the learners and the teacher. That might be the cool part for teaching this way. That might also be the radical part of this teaching. It's not to push the learner to arrive at certain point, rather it is to keep the learner motivated, intrigued, to find the reason when no teacher is asking her to do so. The point is not to have the knowledge wrapped up and consumed by the learner; it is to open the learner to the real situation and to keep exploring.

Instruments

Apart from various tools for exploring, we had chance to see and use rather advanced real instruments: museum visit, observatory tour, seeing through Galileoscope, and setting-up a real big telescope. I was overwhelmed by the variety of instruments we saw in the Harvard museum. After a long time looking at each of the different instruments randomly, I started to notice two instruments, one was labeled as being used for locating star and I didn't find label for the other. I didn't really explore how they could be used for locating stars; actually, I was simply comparing the two pieces. A lot of details were revealed by comparing them, such as if both of them had a compass, and the usage of the setting tube filled with water. At this point, Elizabeth told me that my classmates used a similar equipment to help them draw the lute. It was a natural connection. I was a little surprised at that moment. I came to admire more about the work of my classmates painting the lute.

Slide rule and compass were instruments that we carried home and played with for a while. In our class, Elizabeth gave each of us an instruction of how to use a compass by Galileo. She asked us to use the compass and instruction to divide a line into several equal parts. I spent a lot of time reading the first several lines and decide to skip the first two paragraphs. Then I found the following instructions easy to follow. So I followed the instruction step by step. Then at some point I found it hard to follow again. However, I managed to continue solving the math problem, which was to divide a long line into equal parts. It was a success. After that I reread the text and I understood it then. Elizabeth was very excited that I made it without understanding part of the instruction. What made me more excited about was that I was able to follow the English instructions.

Later when I was trying to learn from my husband how to use a slide rule, I was frustrated. I always felt a conflict between his pace of teaching and my pace of learning. I kept saying I didn't follow you. To be fair, he could be more patient. But I still had trouble with his steadily seamless speeches. And finally as soon as I had a sense that I knew what he was talking about and how to do multiplication with the slide rule, we both stopped, feeling relieved.

However when I was making a slide rule my self, I felt no pressure and in full control of my activity. Although I knew how to use a slide rule to do multiplication by then, I was excited during the process while I was making my own slide rule following the instruction. "Ah, this is how it works!" In the middle of 1 and 2 is not 0.5, but square root of 2! I am still amazed at the power of the slide rule and don't feel that I understand it. I feel I want to play with it for more time.

The different learning experiences that I got about slide rule made me think about the role of teaching. My slide rule teacher was well-intended, patient, but I didn't feel want to learn from him. I felt that at certain point of my exploration, it was harmful to talk to people, it was better for me to be alone; at other times, I felt eager to learn from others and to have others to share with me my findings.

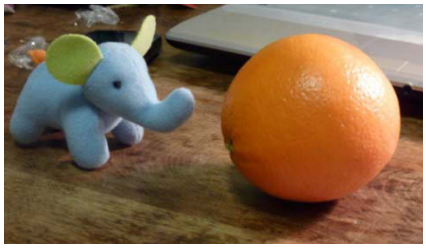
I am still uncertain about the role of mathematics in Galileo's scientific discoveries. We visited thousands of slide rules. The curator told us that the world was built on slide rule. What does that mean? What was the relationship between mathematics and modern science? At Galileo's time, demands for calculation were from military use,

voyage, and maybe something else that I didn't know. A lot of Galileo's researches seemed to be responses to meet those demands. Yet, what does that relate to his most significant contribution to modern science? I remember in Drake's brief sketch of Galileo's career, he mentioned that Galileo was very cautious about publishing his observations and he would publish until he had proved them theoretically. Does this mean to prove mathematically? What is the nature of mathematics?

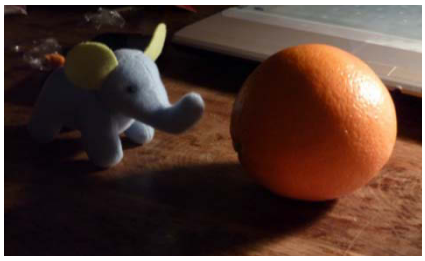
When we were visiting Wallace observatory, looking at the sky with so many stars, I asked Elizabeth, can you tell the name of every star? I knew it was an impossible mission. My real question was related to how to locate the star despite its movements. How can you be sure that you don't mistake them? MC said she saw an orange star last night, we were looking for it over sky; Elizabeth suggested that it might be Mars. Where was Mars then? It was not very easy to find it. When finally Elizabeth was sure that which one was Mars, I said, so the one that was quite alone was Mars, right? Elizabeth looked at me and didn't give me an answer immediately. Oh, no, I said, because the stars move upon the sky. I was hoping to stick a label to it, so that I will never miss it. Unfortunately, I couldn't. And according to Elizabeth, the Orion disappeared during summer time. I was shocked. Won't they stay at the same place every night? I wanted to see if it is so. All these thinking and conversation was related to star location, and a couple of days ago, I observed the star location instruments! Now I feel a real need to find out how it works to locate a star.

I will never forget the moon that I saw through the telescope in Wallace Observatory. It was so beautiful. Those perfect circles, exquisite, thin and even. I also tried to notice what TT saw that Galileo described in Starry Messenger. It took me a long time to look at part of the edge, to notice the subtle change. I was not sure if my expectation would compromise my observation. I focused on two half circles and saw them growing slightly fuller very slowly. I also saw a tiny piece, like a dust near the edge. I didn't keep looking at it closely. Later, when I claimed that the two circles were getting slightly fuller, I said that I noticed that the small dust disappeared. I also inferred that the moon was going to be a full moon several days later. That was right. Now I was thinking about the dust. It should not have disappeared. It should grow as well. I realized how easy it was for me to make unreliable observation. And how hard it was for Galileo to make reliable observations and build theories upon it with relatively poor instruments.

I enjoyed observing common ordinary things around me. I feel that in observing ordinary things going on, I have the most natural mind, I don't need to do things artificially, and in such conditions I might come up with some new findings, which is really fun. Based on our telescope observations, the moon had become very concrete, near, and clear to me. Its rough surface, edges were so real. Inspired by perspective artists, I decided to draw. One night I decided to draw an orange and an elephant. In my room, there were two lights on, they were from different directions.



When I looked at the orange and tried to draw it, I realized that I could view the orange as the Moon. They were not the same but it will be fun to observe the light effect on the surface of the orange under one light source, so I turned the light on the left hand off.

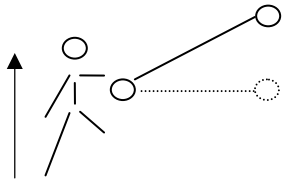


Now it was really exciting to draw the denting part of the surface and the shadow. While watching the Moon at Wallace Observatory, I asked Elizabeth if the dark part of the Moon that Galileo drawn could be seen. Don't expect Elizabeth to tell you the answer. She was listening and MC replied that, "Yes! You can, when the Moon is not full moon yet." That was an interesting point. But I didn't see the dark part even when it was new moon. Maybe I can see it through the telescope? Later after Elizabeth looked at my drawing of orange and elephant, listening to me describing the different light effects that I observed, she commented that maybe the trunk of the elephant could tell you something. This is also an interesting point. Later, when Elizabeth got to see the real photo, she pointed to me that the light effect of the trunk was not as obvious as in my painting. My response is, please change an angle while looking at the screen of computer. It should be discernable.

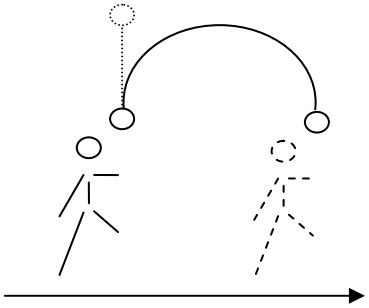
I also paid attention to my daily environment; I took picture of several scenes because I found them as similar to the orange, or the Moon, although the branches and the building didn't have a ball-like shape. It was simply a joy to notice the pattern of "the moon" almost every where.

Motion

I had a lot of fun doing motion experiments. The first interesting thing to do was re-create Galileo's horse riding experiments, which he described in Dialogue. I was walking around the classroom and observed what my classmates were doing. I notice that MC was trying to spin the mirror bowl and rolling balls in the bowl. I asked her if she was trying to watch two motions going on at the same time. Yeah! She said. Then we decided to imitate horse-riding. It was exciting. If I throw a ball to my left while I was running, the ball would not travel in a 90 degree angle to my route, instead, it would go a little toward my motion direction.



If I toss the ball upwards while running, I can still catch the ball as if I was standing still. The ball didn't travel in a direct up-and-down route; instead, it went a semicircular-like route.



This was totally strange, counter-intuitive, and fun. This was like Galileo's example of throwing thing up in a boat. This also is the way everything moves on the earth while the earth is rotating all the time.

The second interesting experiment was developed based on TT 's observation of running vehicles. She noticed that the tire got blurred while the wheel speeded up. So it can roughly tell the speed of the motion. I was not very surprised at this observation, but later when I came to read Settle's paper analyzing Galileo's observation of acceleration of rolling ball on the inclined plane, I found it very interesting. According to Settle, Galileo might have been convinced that the rolling ball along the inclined plane got acceleration as it was rolling because he could hear the changing sound of the iron ball. Some time later, I realized that if it was a tire rolling along the inclined plane, one can tell the acceleration by seeing the tire getting more and more blurred. I tried it out with a spool of tape. First I made some mark on it so that it looked like a tire, and then I rolled it down the inclined plane. I was not surprised to see the acceleration, but very much proud that I invented a new way to sense the acceleration.

The ramped track fight was definitely another great fun. This time JF was attracted by my game, the rest of the classmates were also watching out competition. There was a curved ramped track with three dips between the two outer ends (Cavicchi, summary, January 27, 2010), what JF and I were playing was to release a ball from each end and see the fight between the two released ball. It was great fun. And later we even high speed photographed this game. It was amazing to see a world being slowed down.

My first experience with motion probably was tossing two balls with different weights. Later when I read Settle's paper, I remember my experience and the experience become more meaningful to me. According to Settle (1996), Galileo didn't reject Aristotle's theory on motion from the very beginning, actually when he first noticed that bodies with different weights appear to reach the ground at about the same time, he came up with an explanation in favor of Aristotle's theory. He proposed that because of the "imposed impetus", lighter bodies fell faster at its early stage of falling, while heavier bodies were less affected. Modern psychologist discovered from their experiments that when people hold two bodies and release them at the same time, they tend to release the lighter one slightly earlier than the heavier one, which explained why Galileo came up with an incorrect explanation.

In my experiments, when I tossed two bodies upwards, I noticed that the different weights would affect my action: my both hands would not give the same strength to the two bodies. Such effect would be hard to reduce because it was quite unconscious reaction. I put my hands together and jump in order to minimize the unconscious effect. It was hard and awkward to jump continually. So I decided to place them on a board, and act on the board, so that the balls could be treated equally.

I felt that my experience was connected to Galileo's free fall experiments in some way. And the sense of connection was thrilling.

Pendulum was a big part in my motion experiences and experiments. It was hard for me at the beginning to play with the pendulum. There was nothing standing out for me. But as I read more and communicated with my classmates about Galileo's experiments, I had become more curious about the pendulum. Just as Sagredo said, "You often give me occasion to admire the richness of nature and her great liberality, when from such common things, or I might even say such base ones, you draw new and curious knowledge that is often far beyond my imagination" (Two New Sciences, p98).

I invited TT to do experiments together since she pointed out a question which I was interested in knowing more. It was Galileo's discovery that the pendulum would sway the same speed despite its amplitude of movement. I always thought it more interesting to ask people to do experiments together. That was exciting. Maybe that was why Galileo liked to demonstrate his experiments to the public. I forgot how we

did that experiment, but I remember that afterwards, I asked what made the pendulum move that way. I meant the period, why did it go that way, from the starting point to the lowest point and then went higher at the other quadrant, stopped at one point and then moved back. A similar question that I had in my mind was if I toss a ball upwards, what made it move upwards, stop moving upwards at certain point, and move toward an opposite direction. What made things move that way? It was a wholly different perspective. I remember that I had the same question when we studied physics in high school. There was a textbook to answer my question, I forgot the answers, but I remember that it lacked a sense of humanity, telling me arrogantly that the right answers were to be recited.

Science and history

I heard an argument about progress in history. The progress, according to this argument, is revealed in textbooks. What people used to spend decades of years to explore and find answer to is now reduced to common sense in elementary or high school level textbooks. That was very true to me at a time. Now it seems to me problematic in at lease two aspects.

First is about reducing history. It seems to be so disrespectful to say that Galileo's, Newton's, and the like, their lifetime work could be presented as several lines of formula or laws. This arrogant reduction also distorts what is considered as science. And this reduction was the source of artificial dichotomy between art and science.

There is value in Galileo's half century's obsession with several issues. The value lies not in reducible laws; instead it was the way of doing science that bears the merit. What drove Galileo in the long journey of exploring was not the title of father of science, nor some final scientific conclusions; rather, it was the activity of doing science that gave him lasting momentum. It was the excitement of encountering unexpected; it was the eagerness to communicate, to express; it was the faith in himself to make sense from the uncertainty; it was also his humility in facing the vast unknown territory. I think what he did might have given him a sense of existence and a sense of inalienable right to defend for and maintain his integrity. He knew he was irreducible. It was his experience that constituted the irreducible, the irreducible process, time, experience, faith, love, and dignity. It was the inherent merit of work that he assumed that gave soil to his integrity, confidence, and courage.

It was the joy inherent in a certain experience that attracted Galileo. That's why he wanted to spend his time in his garden, working as a farmer. That's why he played the lute and drew paintings. I would say it is the same intrinsic value of science that accompanied Galileo along the way. For Galileo, there might be little place for instrumental values that were external to the activity itself. Isn't this giving significant implication to teach morality and integrity, science and art?

Second is about progress. Who make the progress? What is determined as progress?

Who has the right to decide? The linear direction of progress is questionable. I would rather take history and the present as continuous. Moreover, I see progress as an outsider's jargon. It is someone viewing from outside of the history of the world that perceives the so-called progress. History is unexpected. There is no predetermined path. And everyone plays a role. Such a role is irreducible as well. I have been told what history was like for a long time. But I didn't get to read the primary sources in history. The history that I have been taught was linear and lead by big figures. Individuals were absent from the picture. But in reading historical texts of the invention of spectacle and telescope, in reading Galileo's correspondence with his contemporaries, I got the refreshing sense of history. I saw the role of individuals, ordinary people in the larger picture. I saw no clear distinction between the work of a craftsman and that Galileo. So many people, whose names were forgotten, nevertheless, they contributed to the collective work of honing skill, achieve knowledge. They are the protagonists in history.

I wrote my reflection on teaching and learning along the part of my own experiments and experiences in this class. For me, it is a start to know real science, to learn more about the relationship between art and science, to think about individuals in history, to ponder over what to teach and how to teach. I remembered that Eleanor Duckworth quoted Barbara Nelson, "You aren't teaching *about* Piaget, you're teaching them to *be* Piaget" (Duckworth, 2006, p85), the best part of this course is that we are not learning about Galileo, we are being Galileo; we are not leaning about science, we are doing science.

One question that stands out most for me during and after our course is about experience. Standing for almost two hours watching the glassblowers working was tiring. I even felt sleepy sometimes, to be honest. What struck me most and was imprinted in my mind was the concentrated, engaged, and calm facial expression of the master craftsman. That state of working revealed to me the value of experience. It must has be decades of years that the craftsman started and built his skills and knowledge doing the work. That many years of experience grew into his body, into his behavior, into his way of living. There must have been various joy, satisfaction, surprises, excitements, frustration, perplexity, expectancy. There must be patience. There must be faith in time. Just like Galileo, who spent decades chewing the handful of questions that he was concerned with. He kept looking for new evidences; he kept returning to his initial inquiry; he kept expanding his territory of exploration. There was no a single, discrete, easily made discovery. Everything was weaved into his vibrant thinking. There was no full stop. Although he made mistakes, his effort, his purposeful trials, left marks in his lifetime, which made him as a person; a person of whom every step was built upon his own previous experience. What drove him forward was the innate rule of his work, which he loved and believed, which could not be distorted by authority, which gave him courage to forge ahead.

Another fascinating issue for me to explore further was "dialogue". Dialogue is

common in science, art, and teaching and learning. Without collective exploration, science is impossible; without expressing and listening, art is impossible; without communicating, teaching and learning are impossible. I remembered my strong desires to share with my teacher and classmates our discoveries, to get inspiration from historical records, to build my experiments on historical readings. I wanted to learn more what LL was exploring, what TT's diagrams was about, and MN new discovery. I believe Galileo was, too, driven by the eagerness to express and communicate with his contemporaries and others in history. As people in our class discussion talked about the importance of hunches, I believe Galileo won't become father of modern science if he was not having dialogues from his predecessors and his contemporary colleagues. Hunch is indispensible, but far not enough. He actually even got inspired by people who claimed opposite point of view. He was not alone. It could be dialogue that gave his exploration meaning and name. It was the nature of dialogue that made his experience being shared by a larger audience beyond time.

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EC.050 Recreate Experiments from History: Inform the Future from the Past: Galileo
January IAP 2010