Mountain Surveying and the Classroom

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The teacher smiled inside as the last bag of M&M's went into the shallow hole in the playground. A few shovel s full of dirt, tamped in so no one could find the hole just by feeling the ground, and the prize was hidden. Not quite – the big blue tarp had to be spread over the hole and surroundings so that the students could not home in on the prize by looking for disturbed soil. Tomorrow, the student surveying teams would use they surveying equipment they had built and the techniques learned – at least presented -- in the mathematics, geography, and history unit the teachers had decided to call Mountain Surveying -- the Railroad to Cloudcroft. Each team would receive instructions written in the terse language of 1898 surveyors, instructions that – if carefully and correctly followed – would lead the team to the exact spot of the prize. Of course, there can be many ways to reach the same spot, and each team would have different instructions to the same end point. One of the other teachers had suggested that the competition take place the first thing in the morning, with each team placing a little flag at the point they reached by surveying. Then regular class work would resume, and at the end of the day, the tarp would be removed and the winning team, the team whose flag was the closest to the true end point, would reap the prize. Of course the students would have their minds on the prize, but much of the day was a review of surveying and surveying techniques, so maybe some of the review would "get inside their brains". Thinking back on the unit, the teacher smiled again. Who would have predicted the wails -- and innovative excuses -- when the teachers informed the students that surveyors in 1898 did not have electronic calculators, and hence, they would not be allowed to use them? And who would have thought that the student who could not multiply two digit numbers could build the best surveying equipment?

[The author's website http://www.lincoln-nf-trails.org has instructions for making inexpensive surveying equipment and materials to help set up a competition.]

I. Introduction

How much could your students learn if they wanted to learn so that they could do something neat? I suggest that teaching surveying, a skill of clear relevance in itself, pulls students into learning to measure angles and distances, to plot maps, to think spatially, to carry out calculations and measurements with care (repeating not because the teacher said so, but because they wanted to do better), and many other skills that are in the mathematics and science standards. If your teacher colleagues are amenable, surveying the Alamogordo and Sacramento Mountains Rail Road can be part of a unit on geography (people and the land) and history (settlement of the Sacramento Mountains).

Your students and you can build an instrument (theodolite) that functions likes the ones used in 1898 in the construction of the A&SM RR. It will not be as precise, but it will cost only $10-15, depending on how good you are at scrounging. The sections below describe surveying language and measurements, surveying equipment and how to make your own inexpensively, and how to use the equipment that you have made.

Don't feel that you have to be historically accurate; feel free to mix modern measuring tapes and a replica theodolite. Do help your kids to learn and have fun. After all, who would have thought that math lessons could build hand and eye skills and allow students blood circulation in their legs?

II. Surveying Notation

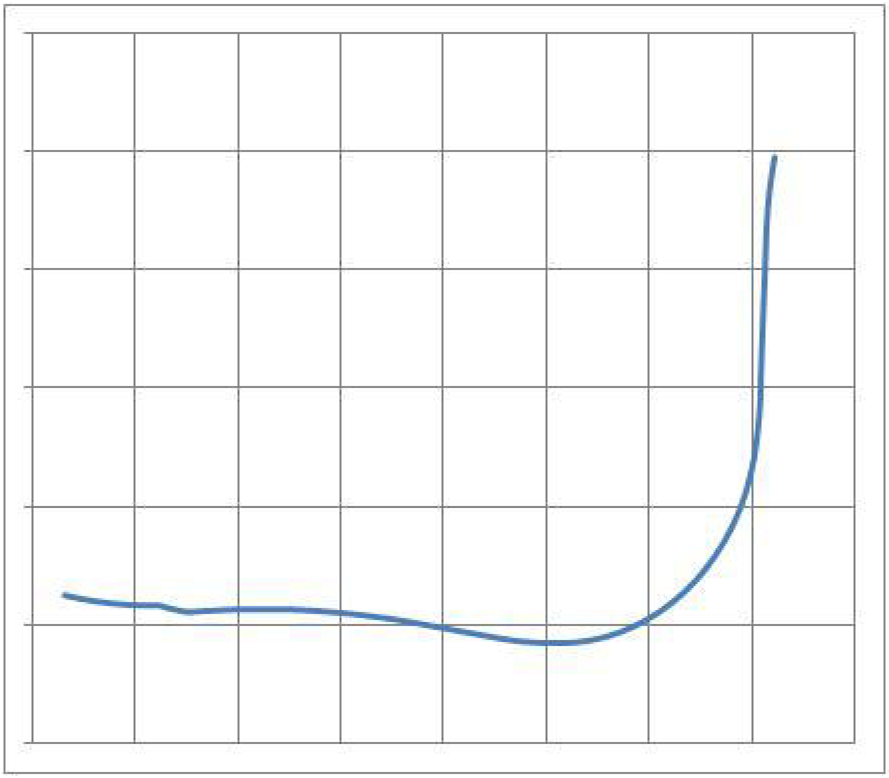
A portion of the A&SM RR between Wooten and Pine Valley was constructed according to the following surveyor's instructions. It looks pretty complicated, but the paragraphs below will help to understand the material.

A	5-6' CHS	893+97.8 P.S.	894+27.8 P.C.C.	Δ=2°30'
B	14° C.L.	894+27.8 P.C.C.	895+19.2 P.C.C.	Δ=12°48'
C	5-6' CHS	895+19.2 P.C.C.	895+49.2 P.R.C.	Δ=2°30'
D	3-10' CHS	895+49.2 P.R.C.	895+79.2 P.C.C.	Δ=1°00'
E	6° C.R.	895+79.2 P.C.C.	897+55 P.C.C.	Δ=10°33'
F	3-10' CHS	897+55 P.C.C.	897+85 P.T.	Δ=1°00'
G	[Straight]	897+85 P.T.	898+53.3 P.S.	
H	10-6' CHS	898.53.3 P.S.	899.13.3 P.C.C.	Δ=9°10'
I	30° C.L.	899+13.3 P.C.C.	901+73.8 P.C.C.	Δ=78°09'
J	10-6' CHS	901+73.8 P.C.C.	902+33.8 P.T.	Δ=9°10'
K	[Straight]	902+33.8 P.T.	903+53.6 P.S.	

The instructions start from a point (station) and tell one how to get to another point. For example, you might tell someone how to get to a friends house by telling the address, 1403 Pine Street, or you might tell them "Start at my house, go three blocks north, turn right, go six blocks, stop at the second house on the right." The railroad survey instructions are like the second set of instructions (and you had better do all the steps right if you want to get to the right place!)

The graph below shows the path described by the instructions given in the table. Each square is 100' x 100'. North is up and East is to the right. The bottom portion of the route lines along the edge of the mountain on the south side of Fresnal Canyon, and the in and out curves show that it follows the contour of the mountain side. The right portion of the route goes from the south side of the canyon to the north side of the canyon, across a broad flat area. The northern tip of the route shown is very near HW 82, just south of the runaway truck turnout.

Aside: Why did the railroad route curve in and out to follow the curve of the mountain side? Prior to World War II and the development of heavy dirt moving equipment, dirt work was expensive in terms of manpower and time. Railroads and roads were designed to involve as little dirt work as possible. If one compares the route and construction of the interstate highways with the older roads that they replaced, the effect is clear. The older roads follow the contour of the land; the interstate highways make use of (sometimes massive) road cuts.



Brief Glossary

Distances are in the format 894+93.5. This means 894 (100' chains) + 93.5 feet = 89,493.5 feet from the starting point. Survey parties carried a standard chain composed of 100 links of one foot each.

C.L. and C.R. mean "curve left" and "curve right", respectively, defined by the surveyor looking away from the initial station.

P.S.	point of spiral, name for the transition from a straight section to a curved section
P.T	point of tangent, name for the transition from a curved section to a straight section
P.C.	point of curvature, name for a transition in which the track continues to curve
P.C.C.	point of compound curvature, name for a transition in which the track continues to curve in the same direction but with different radius of curvature
P.R.C.	point of reverse curvature, name for a transition in which the track continues to curve but in the reverse direction
CHS	chords 5-6' CHS means 5 chords, each 6 feet in length
Δ	change in the bearing The bearing (measured with a compass) is the direction along a (straight) section. A bearing of N74°14'W means "74°14' from North towards West".

With this understanding of terms, we can now read the surveyor's instructions.

Line A Lay out five 6’ chords, each of which deviates from the previous bearing by (2°30’/5 = 30’), so that the total change in bearing is 2°30’. Note that the difference in the cumulative distances is 30’ = 5 x 6’.

Line B Lay out a left-curving arc of a circle so that the bearing changes by Δ=12°48'. The radius of curvature of the circle corresponds to “14°”. This is a tougher concept; it means that the radius of the circle is such that a 100’ chord subtends an angle of 14°. See the reference material for diagrams on this concept.

Line C Same as line A. However P.R.C. says that the next section, described in line D, will curve in the opposite direction.

Whoa! How do we know which direction curves in line A and Line C are bending? In this terse language, those curves are attached to the C.L. in line B. They are both left-curving.

Lines D, E, and F These lines can be understood using the material for lines A, B, and C.

Line G Line F ended with P.T, so the next section (Line G) is straight. How long? I calculate 68.3 feet. There is no entry in the “bearing change” column, not even a zero. Note that the word “straight” is in square brackets. In fact there would be no entry in this column, since the P.T. tells you that the next section is straight.

Lines H, I, J, and K These lines can be understood using the material previously given.

Line I is of particular interest. A 30° curve corresponds to a radius of approximated 194 feet. It is a very sharp curve for a railroad. The Mexican Canyon Trestle, visible from HW 82 just west of Cloudcroft is built on a 30° curve.

III. Equipment (for modern version of mountain surveying)

A. List

1. Angle Measuring Equipment: Theodolite

2. Distance Measuring Equipment: Chains, Tapes

3. Positioning Equipment: range pole, stadia rod

4. Position Marking Equipment: Pins, Stakes, Labeling Materials

5. Recording Equipment: Data Book, Pencils

6. Other Equipment: Levels, Hammers

B. Construction

1. Theodolite

A theodolite is a device for measuring two angles, one in a horizontal plane and the other in a plane perpendicular to the horizontal plane. A transit is a theodolite in which the telescope can be rotated 180° to sight in the reverse direction without affecting any other positioning. The theodolite head – containing the devices for leveling and for setting bearings and measuring angles – is generally mounted on a tripod. The entire apparatus – with the exception of the compass needle – should be made of non-magnetic materials.

A theodolite such as might have been used in surveying the A&SM RR, is shown in the figure below (T.U. Taylor, Surveyor's Handbook, page 39). The top of the tripod is visible at the bottom of the figure. At the base of the theodolite, are three leveling screws. On the circular base are two bubble levels , a large compass, and measuring marks for angles. At the top of the theodolite is the telescope, with its own bubble level, and a protractor for measuring its deviation from horizontal. The telescope assembly can be rotated about a vertical axis to point to objects at different bearings and about a horizontal axis to sight on different heights.. The metal parts –excepting the compass needle -- are made of brass. An instrument of this quality would also have included verniers for measuring angles with increased precision. The instrument described in this material includes all the functions of the instrument shown, with the exceptions being the use of a sight tube rather than a telescope with lenses and the absence of verniers.

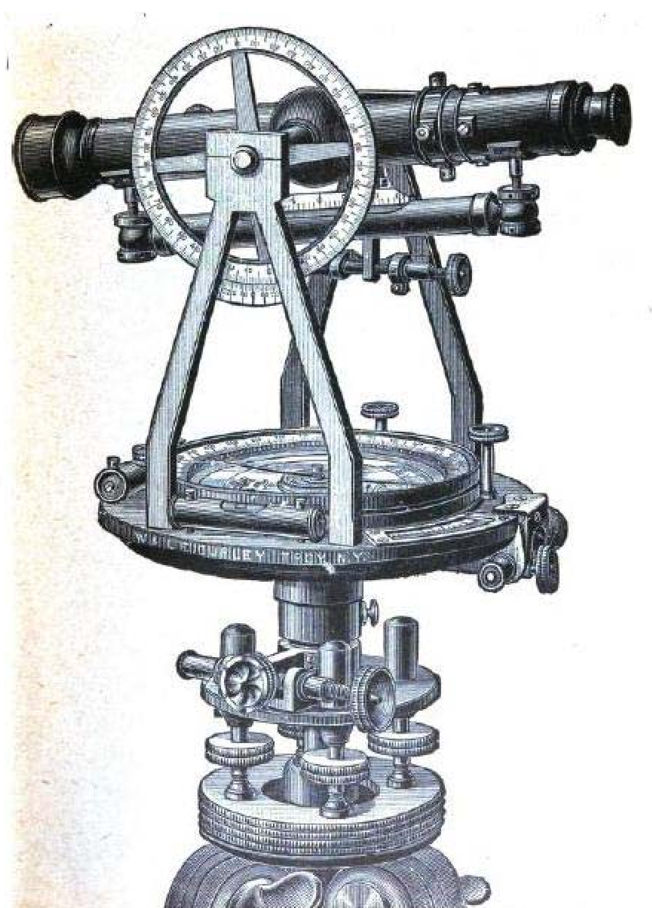


Fig. 24.

Note to teachers: Safety. Safety. Safety. I think the theodolite and other items can be built by students in a class room. No power tools are required. The most significant danger is in the cutting operations with a saw or PVC cutter.

Parts list for the inexpensive theodolite:

I have listed suppliers merely as a guide to sources and costs. Prices are "before tax". I have no financial interest in any of these companies. I encourage you to acquire parts cheaply and effectively, including shopping around and BBOS [Beg, borrow or steal.]

1	Camera tripod [This tripod has a hook at the bottom of the shaft – nice for hanging the plumb bob!]	Walmart	$28.00 each
1	¼-20 nut (preferably non-magnetic)	Lowes, nylon	$0.56 for bag of two
2	4" PVC drain caps	Lowes	$1.95 each
3"	4" PVC drain tube	Lowes	$7.35 for 10'

Note: The previous two items are NOT the normal household plumbing PVC piping and fittings. They are for drain and irrigation. The household plumbing versions fit together tightly, and they are not appropriate for the theodolite project, in which these pieces must allow for rotation. In the Lowes where I shopped they were stocked in the garden section not the plumbing section. In the Home Depot they were both stocked in the plumbing section.

Note: In order to get 3", you have to buy 10' (and have the remainder taking up space). If you contact me, I will give you a 3" piece.)

4	¾" PVC couplings (slip joint)	Lowes	$0.14 each
2	¾" PVC elbows (90°, slip joint)	Lowes	$0.31 each
1	¾" PVC cross (slip joint)	Lowes	$1.70
3 feet	¾" PVC tubing (heavy wall)	Lowes	$1.91 for 10 feet

Note: If you build the theodolite, one chain (with poles), and a range pole, you will need to buy three 10' lengths of ¾" PVC. You can cut the amount needed for the theodolite from the other pieces.

1	protractor	Walmart	$1.79
1	line level, Stanley 42-193	Walmart	$1.47
1	brass wood screw and washer Note: The first "brass screws" that I bought turned out to be steel coated with brass. Check your screws and washers to see whether they affect the needle of your compass when you move them in the vicinity of the needle – brass will have no effect.	Lowes	
1	magnetic compass		

Note: A hiker's compass, available at Walmart for about $6, is much better than is needed. I bought a bunch of simple compasses (about 1 ¼" diameter) for about $1 each, and they work very well [I will sell at cost]..

copper wire
rubber bands
black thread
manila folder (or similar light weight cardboard)
paper clip [used in an earlier version, no longer needed]

Tools and Other

You probably do not need to buy tools for this project. Use your tools, or those of a friend [BBOS]

Saw or PVC cutter [Sawing PVC results in lots of "PVC dust", which can be removed with sandpaper. A fine-toothed saw works better. The PVC cutter costs $10-12, does neater work, but may not be of any further use to you.]
High Temperature glue gun and glue sticks
Compass (for drawing circles)
Ruler
Screwdriver
Pliers
Scissors (for cutting paper)
Rubber cement (or similar for gluing paper to paper. I also used spray glue.)
Coarse sandpaper (40 or 60 grit)

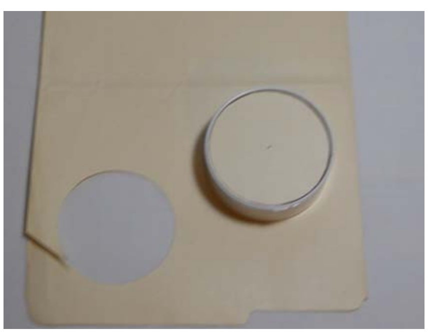
You do not need the PVC cement that is used in plumbing projects.

C**onstructing the Theodolite**

Big Time Advice: In order to be able to make accurate measurements with the theodolite, everything has to be precise. Get the hole precisely centered. Get the couplings vertical. Get the center of the protractor at the right place. Everything!

T-Step 1: Marking the centers of the two 4" PVC caps

Using the manila folder and the drawing compass, draw a circle that is likely to be the right diameter to fit precisely inside a 4" PVC cap. Cut out the circle and see whether it fits. If it is too loose, the next attempt should be larger. If it is too big, the next attempt should be smaller. When you have the Goldilocks circle – This one is just right! – use the pointed end of the compass to make a small mark in both 4" PVC caps. On one of the PVC caps, mark the center on the non-cupped side. The mark can be made more visible by twirling a pencil lead in the hole. Be sure to save the Goldilocks circle – you will need it later.



T-Step 2: Mounting a 4" PVC cap on the tripod

My camera tripod has a "shoe" with a ¼-20 bolt in it. In normal use, this bolt screws into the bottom of the camera. Use the high temperature heat gun to melt a hole in one of the 4" PVC caps [the one that is marked on in the cupped side]. The hole should be just big enough for this bolt to go through. Push the bolt through the 4" PVC cap and tighten the ¼-20 nut onto the bolt. Tight! – you do not want this assembly to rotate at all. We will name this "PVC cap – A".

Note: The bolt in the shoe contains iron. I could not get this bolt out so that I could replace it with a brass one.   Fortunately, it is symmetrically located in the theodolite, and about 3” away from the compass, and that should minimize the problems.

T-Step 3: Cutting and sanding PVC tubing

From the ¾” PVC tubing, cut two pieces 6” long [vertical supports], two pieces 5” long [sight tubes], and two pieces 1½” long [horizontal axles]. The lengths do not have to be exact, both members of a pair should be the same length within 1/8”. CAUTION : If you are using a PVC cutter, it can take substantial hand strength, particularly in getting the cut started. Using both hands is fine.

Now comes the most onerous part of the whole project. Use the coarse sand paper to sand [reduce the diameter] one end of each of the vertical supports so that it will rotate freely but not loosely in the PVC couplings. Do the same with one end of each of the horizontal axles so that it will rotate freely but not loosely in the PVC elbows. This will take some time and effort since PVC is pretty tough.

T-Step 4: Attaching the couplings to the other 4” PVC cap

If these steps are carried out carefully, then the center of the sight tube will be directly over the center of rotation of the apparatus, and accurate measurements can be obtained. If not, ….

Carry out this operation on a FLAT surface. It is OK to put a newspaper on the surface to protect it, but the surface must be flat. Place the 4” PVC cap on the surface, with the cupped side down. Use the Goldilocks circle to locate the center of the cap and mark the center. Draw a straight line through the center [diameter], and extend it all the way to the edges. Draw a diameter on one end of each of the two couplings. You can set this well enough by checking to see whether the diameter you draw divides the circular end into two equal semicircles.

Place the two couplings touching the 4” PVC cap, with their axes vertical. Carefully align the couplings so that the diameter that you drew on the 4” PVC cap and the diameters you drew on the couplings seem, when viewed from directly above, to be one straight line. For the gluing operation, hold one coupling in place, and put just enough glue on it and the cap to hold it in place. Wait for the glue to cool thoroughly.

Now do the same for the other coupling. Once the couplings have been lightly glued to the cap, you can pick up the assembly and put a substantial bead of glue along the line where each coupling touches the cap – both sides. Now the assembly will be both aligned and rugged. We will name this “PVC cap – B”. It is always used with the cupped side down.

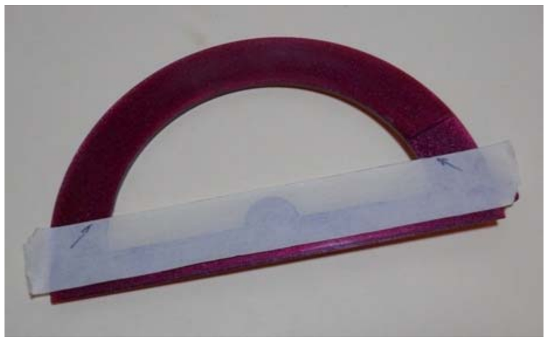
T-Step 5: Assembling the Sight Tube

Push the non-sanded ends of the two 1½” pieces of PVC tubing into opposite openings of the cross. You may need to tap on them lightly with block or hammer to get them all the way in. Do it right the first time – it is difficult to get these pieces out. Push one end of each of the 5” pieces of PVC tubing into the other two openings of the cross – all the way in. Glue the line level to one side of the tube. It should be just the length of the cross. Make sure that it is centered and parallel to the axis of the sight tube. Warning – make sure that the bubble is to the outside, away from the axis. Nice thing – hot glue can be remelted, so if you do not get this just right the first time, you can fix it. Note: I used a pair of pliers to break off the tabs on the under side of the line level – it just seemed to make for a neater look.

T-Step 6: Attaching the protractor to the sight tube

This is a tough step. It is not too hard to glue the protractor to the sight tube; but it can be tough to cut the protractor so that the center of the angle measurement is on the axis of the sight tube. Not all protractors are the same, so general instructions are given, which must be adapted for your protractor.

The outer diameter of ¾” PVC tubing is 1 1/16” (one and one-sixteenth inch). Half of this is 17/32”. The protractor must be cut so that the center of the angle measurement is precisely on the axis of the sight tube. This means that one must draw a line on the protractor 17/32" from the center of angle measurement toward the arc of the protractor, parallel to the base of the protractor. Then, using a fine saw, the protractor must be cut along this line. Since the protractor is likely to be plastic, and plastic can shatter or crack when sawed, it may be best to use rubber cement to glue the protractor to a thin piece of wood, saw the protractor-wood assembly, and then remove the protractor.



Once the protractor has been cut, use the glue gun to attach it to sight tube assembly, on the side opposite the line level. Use your judgment to place it along the center line of the sight tube, with the 90° mark precisely above the center of the cross. Once again, hot glue can be remelted, so mistakes can be fixed.

T-Step 7: Having Middle (of the making) Fun

We will assemble the theodolite (what he have thus far) and move the parts. We will pretend that it is ready, and "make some measurements".

Insert the non-sanded ends of the of the 6" pieces of PVC tubing into the elbows – all the way in. Then insert the sanded ends of the 1½" pieces of PVC tubing, now part of the sight tube assembly, into the other holes of the elbows. Finally, holding the partial assembly to keep it together, insert the sanded ends of the 6" pieces of PVC into the couplings that you attached to the PVC cap -B. Put the 3" piece of 4" PVC drain tubing into PVC cap –A and work the PVC cap-B assembly onto the other end of the 3" pieces of 4" PVC drain tubing.

Now move the parts. The assembly rotates, the sight tube goes up and down. Sight on something distant, and think about how neat this will be when it is finished.

Take the (partial) theodolite apart so that we can work with PVC cap-B. Wiggle the joints where the sanded PVC tubing is in place, and they will gradually work loose.

T-Step 8: Putting a Line on PVC cap-B, parallel to the sight tube

In order to read the bearing for the sight tube accurately, we need a line on the surface of PVC cap-B that is parallel to the sight tube axis (when the sight tube is horizontal). One way to do this is to rely on the quality of our prior construction work, in particular the positioning and alignment of the two couplings attached to PVC cap-B.

Place a ruler against the two vertical supports and draw a line on PVC cap-B, all the way across. Draw a second line, perpendicular to this line and through the (marked) center, all the way to the edges. We will make use of this line after the compass dial is in place.

T-Step 9: Putting the compass dial in place.

We need a compass dial. I did a search in Google using the term "compass dial", and you should do the same. I selected one that I liked (compass_dial.png) and downloaded the file. Getting it to print out just the right size was frustrating. I finally used the following technique. Open a Word file, insert the compass dial image into the Word file, and use the size controls to set the image size. After just a bit of work, I was able to print out a compass dial that fit neatly onto the Goldilocks circle. [See, I told you to save the Goldilocks circle.]

Cut out the compass dial, and use rubber cement to glue the compass dial to the Goldilocks circle. Use a red pen (or something similarly bright) to draw a radial line at the North position on the compass dial – this will help make precise readings later. Screw the brass wood screw and washer through the center of the compass dial and into the center of the PVC cap-B. Tighten the screw so that the dial can be rotated easily but stays in place when released. If you are using a slot head screw, the slot should be parallel to the line drawn in T-Step 8.

T-Step-10: Marking the line with a thread

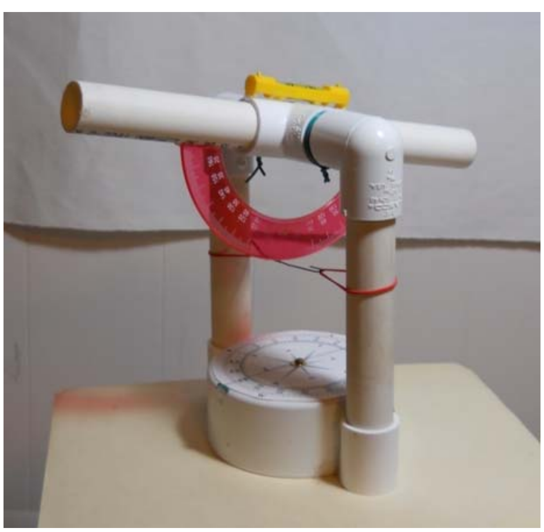
Cut two ¼" pieces of bell wire and glue them to PVC cap-B perpendicular to the line drawn in T-Step 8, at the outer edge, not touching the compass dial, on the top of PVC cap-B. These wires will keep the thread off of the compass dial.

Cut a piece of thread approximately 6" long. Glue one end to the side of PVC cap-B so that it will pass precisely over the line drawn in T-Step 8. Pull the thread to the other side of PVC cap-b, so that it lies in the slot of the screw and passes precisely over the other end of the line and the wire. Hold it just taut and glue it to the side of PVC cap-B. Trim the ends of the thread as needed.

T-Step 11: Centering of the Sight tube

The next step is to center the axis of the sight tube directly over the center of PVC cap-B.   Reassemble the theodolite head. Do not place it on the tripod. Make sure that the two pieces of PVC tubing that make up the sight tube are straight along the same axis, and adjust them if need be. Move the sight tube to the vertical and sight down on the center of PVC cap-B. If the center of the PVC cap-B is not precisely in the center of the sight tube, wiggle the sanded tubing in the elbows, and adjust the position of the sight tube until the centers are the same. Be sure to keep the keep the two vertical supports precisely vertical while adjusting the horizontal pieces.

The centers are aligned, but something must be done to keep them aligned. I used bell wire (copper wire with insulation, used to be used for wiring door bells), and wrapped enough turns into the gap between the elbow and the cross to hold the size of that gap. I then twisted the ends of the wire together so that it could not unwrap. I did this for both gaps. This keeps the sight tube centered over the center of PVC cap-B.



T-Step 12: Completing the sight tube

You have two remaining ¾" PVC couplings. One will have cross hairs and the other a pin hole.

Cross Hairs
Cut a piece of thread 4-6" long. Glue one end, then, holding it taut, glue the other to make a diameter across the end of one of the couplings. Cut another piece of thread and glue a diameter perpendicular to the first – be precise, hold the thread taut. Tirm the thread as needed.

Pin Hole
Use the drawing compass and manila folder, and as in T-Step 1, cut out a circle that is precisely the outer diameter of the other ¾" PVC coupling, and use the rubber cement to glue it to the coupling.

Assembly and Adjustment
Put the two couplings on the ends of the sight tube – do not push them on all the way, you want to be able to remove them. Rotate the cross hair assembly so that the cross hairs are vertical and horizontal. Enlarge the pinhole so that you can see through it easily – I ended up with a hole about 1/16" in diameter. The photographs below who the two ends.

T-Step 13: Providing precise reading of the protractor

Cut a 4" piece of copper wire and bend it so that it is straight in the middle section with hooks on each end. Dissemble the theodolite head and place a rubber band over each vertical support. Hook the ends of the copper wire into the two rubber bands. Reassemble the theodolite. Adjust the rubber bands on the vertical supports so that the copper wire is horizontal and very near to -- but not touching – the protractor.

It is important that the copper wire lies along a line directly between the two vertical supports. With rubber bands of the right size and tension this can be achieved.

T-Step 14: Attaching the compass (optional)

The inexpensive compass is small can easily be lost – particularly in tall grass. I used the glue gun to attach a piece of sting to the side (important) of the compass and tied the other end of the string around one of the vertical supports.

T-Step 15: Having Finished (with the Making) Fun.

Put the theodolite head assembly onto the tripod. Sight through the pin hole on and place the cross hairs on something reasonably distant. See how precisely you can aim at an object. Congratulate yourself, and start having fun. You will have even more fun when you learn how to use the instrument well in Section IV Techniques and Procedures.

2. Plumb Bob

Parts List for the Plumb Bob [You can pay $8-10 for a fine brass plumb bob, or you can make a good enough one for more or less nothing.

String
Copper wire
Non-magnetic weight (old brass plumbing fittings, such as gas fittings do fine – remember BBOS)

Tools:

Pliers
Glue Gun and glue sticks

PB-Step 1: Bending the wire

Bend the wire to look approximately like the figure, with a loop to hold the string, a tangle to hold the wire to the glue, and a short straight piece.

PB-Step 2: Assembling the Plumb Bob

Push the straight wire through the hole in the fitting. Add hot glue to hold the wire in the fitting. Remember that the plumb bob needs to be near symmetric with the straight wire aligned along the path of the supporting string.

2. Chain

In the late 1800's the standard for distance measurements in rough environments was the Engineer's chain, 100' long, consisting of 100 links each 1' long. Figure xxx shows a similar chain. By the early 1900's it had been replaced by a steel tape, wound on a reel, which is lighter and provided greater accuracy. The older equipments still affects the language, as for example, phrases such as "the distance was six 100 foot chains". The notation in Section II counts the number of 100' chains.

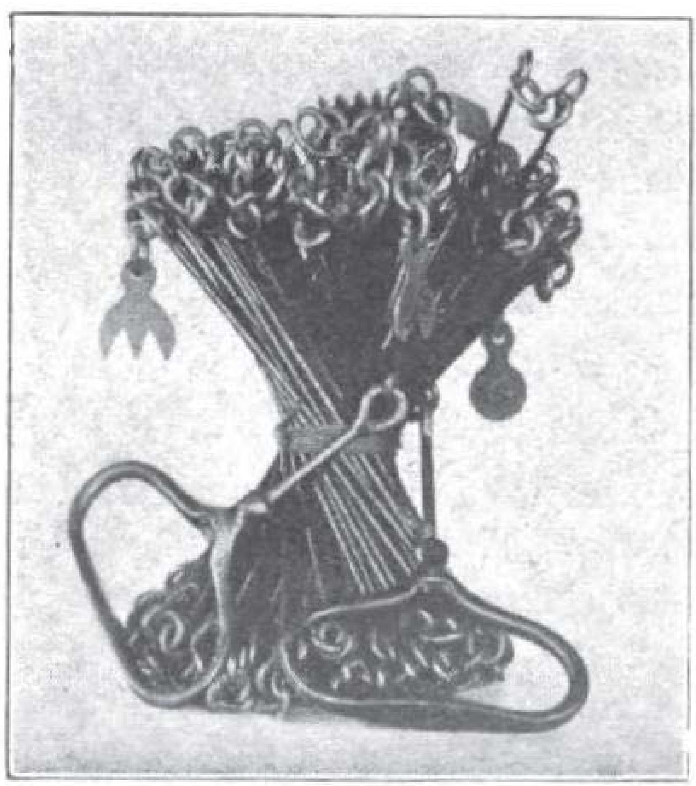


Fig. 1.

(T.U. Taylor, Handbook of Surveying, page 2.)

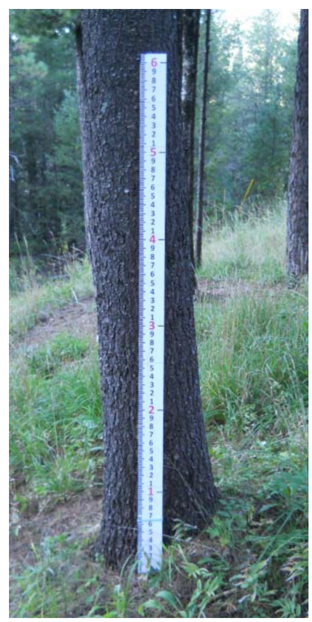
I made a 10 foot chain out of lengths of coat-hanger wire, just to show a model of the older unwieldy chain. I recommend that you use any of a variety of widely available steel measuring tapes.

The actual length of a measuring chain or tape depends on the temperature, the tension on the chain or tape (for example, an unsupported chain across a ravine), wear, and other factors. Professional surveyors know how to deal with these matters, but such corrections are not part of this material.

3. Range Pole/Stadia Rod

A range pole is used for basic sighting in surveying. It is pole with alternating one foot red and white sections. It doe not enable one to measure changes in elevation. A stadia rod is required to measure changes in elevation, and it is required for mountain surveying.

A stadia rod has the distance from the surface of the ground marked on it. A standard stadia rod in use in 1900 was 3.5" wide, ¾" thick, and 12' long, hinged in the middle so that it could be carried easily. A key problem was to present the numbers so that they could be read correctly at the distances encountered in surveying.



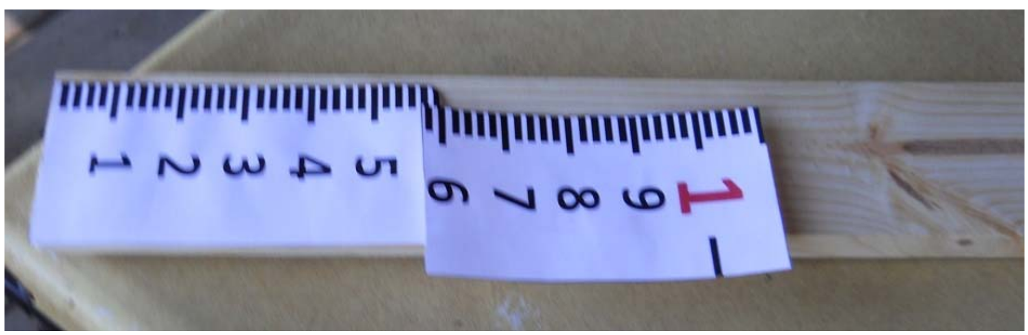
The following text is adapted from T.U. Taylor, Handbook of Surveying, page 119 to describe the scale on the stadia rod we will construct:

The foot marks are indicated in red figures 1.25 in. high, while the tenths are indicated by black figures 0.75 in. high. Each red figure is bracketed by two black strips 0.75 in. long, and the figure refers to the *top* edge of the strip and indicates its distance from the bottom of the rod. In the same way, each black figure is opposite a single 0.75 in. long, black strip, the black figures indicating the distance in tenths of a foot to the top of its strip from the red figure below. The space between the black figures (the top through the black lines) is divided into ten equal spaces alternately painted black, while the white background forms another strip of the same width. If the wire reads between the red 3 and 4, between the black 6 and 7, and is at the top of the third black strip, the reading is 3.66. It is well to remember that the top of the short black strips (about 0.5 in. long) indicate even hundredths, i.e., .02, .04, .06, etc., while the bottom of the black strip indicates odd hundredths.

The rod that Taylor described is differs slightly from the one we will build. The rod Taylor described could be used at distances up to 600 ft; of course, the theodolite had a telescope rather than a sight tube.

Obtain 1 six foot length of standard 1" x 4" lumber (2 such lengths if you want a 12 ft. stadia rod). A 1" x 4" (planed) is actually 5/8" x 3 5/8", very close to the dimensions that Taylor describes.

Print out as many pages as needed from the file Stadia Rod Scale.ppt. Start with page 1. Cut out the two pieces printed on the page and glue them onto the 1" x 4" with 1-5 scale flush with the end of the board. Glue the 6-9 scale so that the appropriate black lines overlap precisely. Repeat this process as many times as necessary, stepping off the foot increments. If the scale looks a bit a bit odd, remember that this is probably the first time you have seen a scale in tenths of a foot.



IV. Techniques and Procedures

A. Basic use of the theodolite

1. Place tripod precisely over the starting point (usually the endpoint of the previous measurement). Lower the plumb bob until it is just above the ground, Since the plumb bob has a narrow point, it can be used to locate the tripod very close (perhaps within 1/8") to the center of the peg. The shaft of the tripod should be as close to vertical as possible. You may want to use a small carpenter's level help align it to the vertical.

2. Place the cross-check level directly over the center of the mounting screw. Since the mounting screw sticks up, us a medicine bottle cap or jar lid, etc. to provide a platform for the cross-check level. My tripod has two perpendicular adjustments for the head, which makes it possible to level the head without further adjustment of the legs. (To set a level plane with the cross-check level, make sure that the bubble in each level is precisely in the middle; the black lines can be used to help eliminate parallax.). If the cross-check level shows level on the platform, then the bottom of PVC cap will also be level.

3. Insert the theodolite head into the PVC cap. Be careful not to avoid affect the leveling done in step 2.

4. Adjust the theodolite head so that when sighting through the sight tube, the cross hairs fall precisely on the object whose bearing is to be measured.

At this time the surveyor must make a decision. If the object is to carry out plane surveying, then the sight tube must be leveled, using the level attached to its top side. On the other hand, if a rise/fall is to be measured -- the gradient for the A&SM RR, for example -- then the angle of the sight tube must be set to build this gradient into the measurements. Set the desired angle on the sight tube. Measure the height of the sight tube above the ground, tell the person holding the pole to set the marker at that height, then sight the sight tube onto that marker. The necessity to include a gradient into the survey work is a key aspect of mountain surveying.

Aside: The builders of the A&SM RR tried to have a gradient of no more than 3%, i.e., a rise of 3 feet for each 100 feet of horizontal distance. I calculate that they would have set the angle of the telescope from horizontal to be 1°43'.

5. After you have sighted on the object, measure the bearing to the object. First it is necessary to rotate the compass dial on the theodolilte so that the N on the compass dial lies at North, as shown by the compass needle.

Using the hiking compass
Place the bottle cap or jar lid, etc on the theodolite surface, place the compass on top of this platform, with its center over the center of the theodolite. Taking care to keep the compass in this position, rotate the theodolite compass dial so that the N on the compass dial lies at North, as shown by the compass needle.

Using the small compass
Place the compass near the N on the compass dial. Rotate the compass dial – and move the compass as needed – so that you can sight along the compass dial N to the center of the compass dial and along the compass needle. When these two lines coincide, the compass dial North is the same as the compass needle North. [The markings on the magnetic compass do not matter; only the position of its needle is needed.]

The placement of the compass disk at the correct position is tricky and important. Carry out this adjustment with a high level of care. In order to get a good view of the compass needle, it may be necessary to rotate the sight tube about the horizontal axis, make the adjustment, and then rotate it back into position; this is acceptable.

Comment: I found it easier to carry out this procedure precisely with the small compass.

Caution: Anything containing iron that is near to the compass can affect the compass rneedle. My metal belt buckle causes a compass on the table to move when I come with three feet or so. If in doubt about the effect caused by an object, bring it close to the compass and check for movement of the compass needle.

Caution: magnetic north is not the same as geographic north, and professional surveyors correct for this discrepancy. At the level of use anticipated for this instrument, it is not necessary to make the correction.

6. Read the bearing on the side of the compass dial away from the viewer, i.e., the side closest to the cross hairs. Report the bearing as "degrees clockwise from north". There are other ways to report bearings, but doing it this way will provide consistent usage.

Note: Sometimes it is necessary to survey a Δ (change of bearing). In this case, set up the theodolite for the previous bearing, rotate the sight tube to the new bearing, and direct the person holding the pole to move to that position.

7. Measure the distance to the object.

8. Record the primary data, as described in the following section.

B. Recording Measurements

1. Obtain a sturdy data book.

2. For each job, create a table of the following form

Station	Description	Distance	Cum. Distance	Bearing	Δ	Other Information
1						
2						
3						
4						
5						
6						
7						
8						
9						

3. The description is information such as P.S., P.T., 14° C.L., etc. The distance is the measured distance from the current station to the next station. The bearing is the measured bearing. Other information, such as gradient, may be entered as necessary. Cum. Distance is the cumulative distance and is a calculated quantity. Either the bearing or the Δ will be a calculated quantity. For example, if Δ surveying is carried out, the bearing will be a calculated quantity.

V. References

Found through Google search on "railroad surveying"

Surveyor's Handbook
By T. U. Taylor
http://www.archive.org/details/surveyorshandbo01taylgoog

Textbook on Railroad Surveying
By George Wellington Pickels
http://www.archive.org/details/textbookonrailro00pickrich

Field book for Railroad Surveying
By C.L. Crandall and F. A. Barnes
http://www.archive.org/details/fieldbookforrail00cranrich

Text book on Railroad Surveying
By George Wellington Pickels and Carroll Carson Wiley

http://books.google.com/books?id=42M5AAAAMAAJ&printsec=frontcover&dq=railroad+surveying&source=bl&ots=1K7WDdyYSj&sig=b5sJsiA2fd0AM6cObs5gQl2gyPE&hl=en&ei=ZymaTL3qEcKclgef17CMBg&sa=X&oi=book_result&ct=result&resnum=10&ved=0CDcQ6AEwCQ#v=onepage&q&f=false

Collections

Internet Archives Search – subject surveying
http://www.archive.org/search.php?query=subject%3A%22Surveying%22

Surveying Books
http://www.surveyhistory.org/surveying_books_1900s.htm

VI. About the Author

Lynn Melton is not a professional surveyor. He taught chemistry at the University of Texas at Dallas for many years, and since 2007 has been a member of the Science/Mathematics Education Department there. He is now on a half-time assignment, which requires him to be in Dallas for the Spring semester, but leaves him free to enjoy his cabin near Cloudcroft and the joys of the Sacramento Mountains the rest of the year.

He has a fervent interest in helping teachers to improve the delivery of science/mathematics material, particularly in the pre-high school grades. He became interested in hiking the route of the old Alamogordo and Sacramento Mountains Railroad – abandoned in 1948 and partially buried under HW 82 -- -- and learned to read the old survey maps in order to find the original route. He has combined these two themes in the hope that "**doing** mathematics, geography, and history" engages and rewards our students.