High Flying Geometry!

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The Science, Engineering and Operation of Drones

Abstract

This curriculum unit has three separate lessons using a drone in a high school Geometry class to bring life to some of Geometry's classic curriculum topics: Using trigonometry to find a height, identifying polygons by their characteristics, and finding surface area and volume of solids. One of the goals is to enliven ancient methods with new technology, not to shorten the topic, but to deepen it, getting students invested in the beauty of the mathematics and perhaps discovering more about their school campus. Two of the lessons entail student teams choosing objects or sites to measure as challenges for other student teams. Student teams are involved in every aspect of the projects, including grading the other team's work and finding the percent error. Instructions, student task sheets and rubrics are all included, as are instructions for creating a clinometer. Two types of drones are recommended: a programmable drone which operates indoors, and a drone with measuring and photography capabilities which can operate outdoors.

Keywords

Drone, drone safety, clinometer, right triangle trigonometry, campus exploration, coding/programing, Blockly for Robolink, CoDrone EDU, DJI Mini Pro 4, fermi questions, area, volume, height, angle of elevation, student challenge, percent error, polygon characteristics

Unit Content

As a math teacher for over 40 years, I have worked to keep up with current technology. Realize, that I did not own my first calculator until I attended college as a secondary education/mathematics major. At college, my computer science course language was Basic, and we typed at a terminal in a room outside the mainframe; our program printouts were on continuous computer paper. In my career I've seen the introduction of desktop computers, laptop computers, 3-D printers, and many generations of graphing calculators. I've been trained in and used learning platforms like GeoGebra, Geometer's Sketchpad, and Desmos. I've taught for years using the constructivist curriculum College Preparatory Mathematics (CPM).

My current school, the Philadelphia High School for Girls has a rich history of women who worked in the birth of computers. Two of our graduates from 1942, Doris and Shirley Blumberg, were recruited by the US Army to work in a secret ballistics research lab at the University of Pennsylvania. As "human computers" they were charged with making complex ballistics tables to assist the pilots as they dropped bombs in World War II. Some of the women in this team, went on to work on the very first computer, ENIAC. Their work was documented in the film "Top Secret Rosies". Just a few years later, another Girls' High graduate, Milly Koss, worked with Grace Harper programming UNIVAC. She received two major awards honoring her work, an Ada Lovelace Award and a Grace Hopper Celebration of Women in Computing.

Now, I am lucky enough to be taking a course in the science, engineering and operation of drones. In our class, we have learned about the structure and physics of a drone, programming a drone and the ethics surrounding drone use. A door to the whole new world of this new technology has been opened for me. Drones were first developed for military use, but according to the NextWave STEM, History of Drones in K-12 Education, recreational drones became available and were used outside of the classroom. In 2015, the cost of drones became more affordable and the technology was improved upon, so a few schools were able to incorporate them in their programs.(*The History of Drones in K-12 Education I NextWaveSTEM*, n.d.)

At the 2016 Society for Information Technology & Teacher Education International Conference in Atlanta Georgia, professors and a graduate student from New Jersey City University, presented their recommendation that drone usage in classroom was vital to engage, motivate and inspire students to learn and grow. They developed a model of implementation, SOAR, to include safety, operation, active learning, and research. The interdisciplinary approach ensures a student-centered approach that also gives full exposure to topics pertaining to drone usage (Carnahan et al., 2016).

At the 2021 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), Siditë Duraj, Lekë Pepkolaj and Gerald Hoxha, presented the article: "Adopting Drone Technology in Mathematics Education". They made compelling arguments and applications on using drones in high school and university math classes. If you need to write a grant to get drones for your classroom, I highly recommend this article as a resource to convince the grantees of the merits of using drones in your classroom or school. In their introduction they contend that since math is often a challenging class for some students, why not use drone technology to solve real-life problems in various topics in mathematics to engage student and allow them to witness the results of their efforts and the power and beauty of mathematics (Siditë Duraj & Gerald Hoxha, n.d.). The authors state, "Drone technology opens a world of opportunities in school, allowing students to actively improve their understanding by integrating analytical knowledge with logic and cognitive skills. Drones have a lot to promise in this regard, as they can help students study science, technology, engineering, and math (STEM) topics in an engaging and enjoyable way."(Siditë Duraj & Gerald Hoxha, n.d.) "Not only can drones provide key data, such as aerial images, but the operation of such a device equips students with foundational knowledge of a growing industrial technology."(Naab & Weigel, 2021)

One aspect of drones in education, which I personally am not addressing in the lessons that follow, is the US Federal Aviation Administration's (FAA) Part 107 Commercial small Unmanned Aerial Vehicles (sUAVs) pilot test. In an article entitled "Preparing Students for Drone Careers Using Active Learning Instruction" it is noted that as drone availability and popularity grow, concerns that pilots without proper training can create threats to public safety and privacy (Lobo et al., 2021). I have included the Title 14-Aeronautics and Space Chapter 1-FAA, Department of Transportation Subchapter F-Air Traffic and General Operating Rules (*Title 14-Aeronautics and Space Chapter I-Federal Aviation Administration, Department of Transportation Subchapter F-Air Traffic and General Operating Rules*, n.d.)and USCODE title 49 subtitle VII part A subpartii-chap 448, §44809 Exception for limited recreational operations of unmanned aircraft (*USCODE-2020-Title49-SubtitleVII-PartA-Subpartiii-Chap448-Sec44809*, n.d.) in my resources.

Teaching Strategies

My curriculum unit will focus on 3 topics in Geometry: Trigonometry, Area and Volume, and Polygons. The advantages of integrating drone technology into these topics covered in most Geometry curricula is for students to be motivated and engaged through hands-on practice, develop spatial visualization skills, sequencing skills, critical thinking, and soft skills, such as teamwork (Siditë Duraj & Gerald Hoxha, n.d.).

The lessons will feature multiple teaching strategies and use all of the eight **Standards for Mathematical Practices**: 1. Make sense of problems and persevere in solving them, 2. Reason abstractly and quantitatively, 3. Construct arguments and critique the reasoning of others., 4. Model with mathematics, 5. Use appropriate tools strategically, 6. Attend to precision, 7. Look for and make use of structure, 8. Look for and express regularity in repeated reasoning (*Common Core State Standards for Mathematics*, n.d.) Other strategies utilized are **differentiated instruction**, **technology based instruction**, **student choice, cooperative learning**, **inquiry-based learning**, **kinesthetic learning**, **experiential learning, reciprocal teaching** and **blended learning**. Students will also pose **Fermi type questions** based on Enrico Fermi's desire to understand order of magnitude rather than exact answers to give real meaning to a number or measure.

Two different drones will be used for the lessons: the CoDrone EDU can be programmed and must be flown inside, while the DJI Mini Pro 4 has a camera, can be flown outside, and has more measuring capabilities. Before beginning the actual Geometry lessons, student teams will learn to fly the CoDrone EDU using a controller.

For the first series of lessons, student teams will challenge each other to use trigonometry to find the height of various landmarks on the schools 2-acre campus. Each team will select and measure their object using the DJI Mini Pro 4 drone. The team receiving the challenge will use a clinometer to measure the angle from their line of sight to see the top of the object and measure their distance from the base of the object. Factoring in the height of the student sighting the object, they will use right triangle trigonometry to calculate the height.

The second lesson will involve programming the CoDrone EDU using one of its languages, *Blockly*. After completing a series of programming lesson on *RoboLink*, CoDrone EDU's lesson platform, student teams will create flight plans to replicate a certain polygon, using its angles, number of sides and side length. Other teams will have to determine what polygon the drone is making.

For the third series of lessons, the class will use the DJI Mini Pro 4 drone to take overhead photos of the school building and campus, measuring the dimensions as it flies. The goal of the lessons will be to find the area and volume of the entire school or certain sections of the school. Students can have fun creating or answering Fermi type questions involving volume such as how many elephants could fit in the auditorium, or if you filled the gym with water, how many hippos could swim in it. Dr. Larry Weinstein, a physics professor and scholar, notes how he fell in love with Fermi in his high school physics class, posed with the classic question "How many piano tuners are there in Chicago?"(Weinstein, 2022). I've included in my resources, a presentation prepared by Patrick Liscio as part of the Math CoOp at Brown University on Fermi Question and Order of Magnitude (Liscio, 2019).

Classroom Activities

Lesson 1: Using a Clinometer and a Drone to Find Heights (1-2 weeks)

Learning Objective: At the end of this lesson, students will be able to find the height of various landmarks around the school campus using a hand-made clinometer to measure angles of elevation, trigonometric equations, and a drone to check the heights. Student teams will create these "how tall?" challenges after using a drone to find the height.

Materials:

- Drone capable of measuring distance (specifically height)
- CPM Geometry Problem T-51 (Appendix 1.1)
- Which One Doesn't Belong do now (Appendix 1.2)
- Pictures of various clinometers and clinometers in use (Appendix 1.2)
- Directions to make clinometers (Appendix 1.3)

- Supplies for making clinometer
  - Paper copy of protractors (Appendix 3)
  - Straws
  - String
  - Stapler
  - Index cards
  - Glue
  - Tape
  - Something to tie on as a weight (such as 1/4" washers)
- Tape Measure
- Height Challenge Project including Grading Rubric (Appendix 1.4)
- Height Challenge Team Challenge Form (Appendix 1.5)
- Height Challenge Project Reflection (Appendix 1.6)
- Calculator
- Permission slip for drone usage and campus access.

Prerequisites:
Students have studied right triangle trigonometry and are able to use the tangent function to find a missing side.
Students understand "Angle of Elevation".
Students are familiar with drone operation usage.

Choosing & Measuring Challenge Site/Object - Procedures:

1. Give the CPM problem T-51 as a Do Now. This problem incorporates the measurer's height as well as all of the other measurements. Make sure to go over the answers as a class.
2. Distribute the Height Challenge assignment and grading rubric. If students are not already in teams, put them in teams of 4 students, either by self-selection or under your direction.
3. Distribute the parent permission slip for drone usage if you have not previously done so.
4. Work with student teams to select their challenge site/object. Make sure it is in a reasonable and safe environment. They can submit their top 3 choices on a google form. This way, the teacher can know who actually selected a repeatedly requested site/object first.

5. Teams will measure the height of their object with a drone. If students are familiar with operating a drone, this should not take too long. Consult your school administration for permission for students to work independently on the measuring, or with the class, visit the sites as each team makes their drone measurements. Submit the object/site details on the designated google form.
6. Have student teams write out their challenge and allow the teams to issue the challenge to another team. You could have this pre-arranged or allow students to select which team they will challenge. I will use a google form to have students submit their object and its measurements.

Making a Clinometer - Procedures:

1. Start the lesson with the Which One Doesn't Belong. This strategy offers multiple entry points for students as there is no wrong answer. It also gets students writing or communicating about why they think a particular item does not belong. I number the placements like the quadrants to ease in identifying the pictures. I usually ask the whole class "who thinks the picture in quadrant 1 does not belong and ask them to discuss their reasoning. They often have talked about this in their teams before it becomes a whole class discussion.
2. After the class has discussed the differences in the items, ask what the items have in common. They are all measuring tools. See if they can identify them if they have not already in their discussions. Tape measure, caliper, thermometer, compass.
3. Introduce a clinometer using the pictures of the instruments as well as the clinometers in use and the description of how they are being used. A clinometer measures an angle of elevation or slope or depression with respect to gravity's direction.
4. Give student teams the directions and materials for building their own clinometer. At your discretion, decide if each person will be creating a clinometer or if pairs or teams of students create a clinometer to share.
5. Have teams report to a measuring station to measure their individual heights and their heights up to their eyes.
6. After the clinometers are made, have students practice sighting objects in the classroom or hallway. They should measure their distance from the object with tape measures or you could have a standard distance marked off and labeled with painter's tape. Teams should record their angles of elevation and distance from each object. You can each student sight the same object or have each student sight a different object.

7. With their teams, back at their seats, students should set up the trigonometric equations needed to solve the object height problem(s). If students are working on different objects around the room, make sure to have the actual heights available so they can check their answers. This is their practice.

The Height Challenge – Procedures:

1. Have student teams deliver their challenge to their selected recipient team.
2. Depending on how you have worked this out with the administration and students, it is time to use their clinometers to measure the site/object in their challenge. They will also need to measure the horizontal distance from the site/object as well as the angle of elevation using their clinometers. Each team member should make their own measurements and have all team members record measurements for every team member. This is a requirement on their grading rubric.
3. After the team members have found the site/object height using trigonometric equations, they can report their findings, or the average of their findings, back to the challenging team. The challenging team will let the students know how close to the actual measurement their team is.
4. Students hand in their work and their reflection of the challenge to the teacher to receive their final grade.

Lesson 1 Notes: *Lesson 1 Notes*: I believe there are phone apps for clinometers, but I prefer students making and using a tangible clinometer. I don't think you would lose too much from the lesson though by using an app. It would save a day or two from the total lesson time.

Lesson 2: Programming the CoDrone EDU Drone with Blockly for Robolink (1-2 weeks)*

* The time allotment for this lesson will depend upon how prepared your students are to use a programming tool and how familiar they are with the CoDrone EDU drone.

Lesson Objective: At the end of this lesson, students will be able to operate the CoDrone EDU using the controller. Students will be able to program a CoDrone EDU using Blockly for Robolink to demonstrate various polygons using drone flight. Students should already be familiar with the properties and characteristics of polygons.

Materials:

- CoDrone EDU Drone(s)

- Getting Started with CoDrone EDU https://learn.robolink.com/course/getting-started-with-codrone-edu/
- Robolink Basecamp https://learn.robolink.com/
- Teacher Resources https://drive.google.com/drive/folders/1c1wbvOnCUzYuZ4SrTbYTSJ5TgTNgmqsg
- Safety glasses for students when using the drone inside the classroom

Procedures:

1. On a Chrome browser, have students go to the CoDrone EDU basecamp course to go through all of the drone basics. It includes not only operating instructions, but lessons for safety and maintenance. There are 7 lessons that vary in length from 5 minutes to 30 minutes, totaling less than 2 hours. There are also accompanying videos that can help students with these lessons. Of course, availability to the drone and controller themselves is vital for these lessons. I recommend the students work on these in teams of 2-4. Depending on how many drones you may have for your classroom, this could be a station activity for teams to rotate through, while the rest of the class is completing a different lesson or activity which does not need to be related to the drone. I will warn you though, that the other students could lose focus while the drones are buzzing about the back of the room. Plan accordingly!
2. Use Robolink Basecamp to go through programming lessons with the students. I recommend using Blockly as opposed to Python to keep the focus on the actual coding. Python is quite particular for input and not every computer can easily pair the Python platform with the CoDrone EDU drone. While coding with Blockly, it is possible to see the Python code by selecting a button on the right of the workspace. In Blockly, there are 8 beginner lessons, 8 intermediate lessons and 7 advanced lessons. Each lesson takes between 30-45 minutes. It is possible to work on coding without a drone attached or paired with the computer, but it is necessary to have a drone attached to test the code.
3. When students are sufficiently literate in programming, present the polygon assignment. Each student team or pair will be assigned a polygon to create with the drone. For example, a team that was assigned an equilateral triangle will program 3 sides with 60° turns. Students can use lights and sound with their coding to enhance their polygon. At the time of the writing of this curriculum unit, there is a challenge of the drone flying to represent congruent sides, because

Blockly can only use time as a measurement with direction. Robolink is hoping to add distance measures to its flight commands in Blockly, as they do exist when coding in Python.

4. Student teams will present their polygon to be graded for accuracy in flight and for the details in the code. Depending on the number of CoDrone EDU drones you have in your classroom, peer evaluation, including identification of the polygon, could also be included.

Lesson 2 Notes: Robolink also provides teacher resources that include premade lessons. The lessons include articles and videos about the topic as well as code for programs. They also note the standards and offer an evaluation. I highly recommend investigating the lessons and modeling your own lessons on them.

Lesson 3: Real Dimensions for Hands-On 2-D & 3-D Measures (3-5 days)

Learning Objective: At the end of this lesson, students will be able to find the area and volume of the school building(s) and other parts of campus by using drone measurements and photographs to find dimensions. Student teams will then create problems of capacity using non-standard units of measure.

Materials:

- Drone capable of taking pictures and measurements
- Map of school and campus layout, including classrooms, gym, cafeteria, auditorium, and playing fields, etc.
- Fermi Question and Order of Magnitude
- Internet access for student teams to access data on sizes of various animals and objects they will use for their own Fermi type unit of measure.
- How Big is Our School Project and Grading Rubric. (Appendix 3.1)
- Permission slip for drone usage and campus access.

Procedures:

1. Introduce the lesson with some questions about the size of classrooms or sites at your school, like “What is bigger, the auditorium or the gym?” and “How many feet away is your math classroom from your English classroom?” You want to gauge students’ knowledge of measurement estimation and their knowledge of the school building.

2. Distribute the project and the grading rubric to the student teams. If they are not already in groups, select them now.
3. With a drone that is capable of taking measurements and photographs, measure the dimensions of the school building and areas of the campus such as fields or playgrounds and the parking lot. For the building itself, the more measurements you can make, the better. You want the height of the building of course, but try to make measurements of each floor. Also try to get measurements for different parts of the building, like the gym area and the auditorium. These measurements can be noted on the copies of the drone photographs. The involvement of the class in this exercise will depend on permission from the administration and the parent/guardians. The teacher should know how to operate the drone and obtain the photographs and measurements. The more students can be involved in this portion of the project, the better.
4. Have students select their area or site around the school and campus. Teams should prioritize and select 3 sites in case other teams request the same area or site. You can have them submit this on a google form.
5. Once a team's area or site has been approved, they will make the calculations for the area and/or volume of their site, using the drone photographs and measurements to use accurate formulas and dimensions. Make sure students are using the agreed upon unit of measure for these calculations.
6. The teams will then select their Fermi-type unit of measure. They will have to research this object to find its average size. They will then formulate their capacity question using their unique unit of measure. Teams will also need to calculate the answer to the question they will pose and submit both the question and its answer to the teacher, so they can distribute them to other teams.
7. Teams will calculate the answer to the capacity question posed to them by another team (but distributed by the teacher). The receiving teams should have access to the dimensions of this space from the drone photographs enhanced with measurements. Teams will submit their answers to the teacher.

Lesson 3 Notes: One of the purposes of using non-standard units of measure is for students to develop a sense of magnitude when discussing the area and volume of parts of the school and its campus. This should also be a project that allows students to have fun while completing a real-world task.

Resources

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Additional Resources

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Appendix

From the Common Core State Standards for Mathematics

Congruence G-CO

Make geometric constructions

12. Make formal geometric constructions with a variety of tools and methods (compass and straightedge, string, reflective devices, paper folding, dynamic geometric software, etc.).

Similarity, Right Triangles, and Trigonometry G-SRT

Define trigonometric ratios and solve problems involving right triangles

8. Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.

Geometric Measurement and Dimension G-GMD

Visualize relationships between two-dimensional and three- dimensional objects

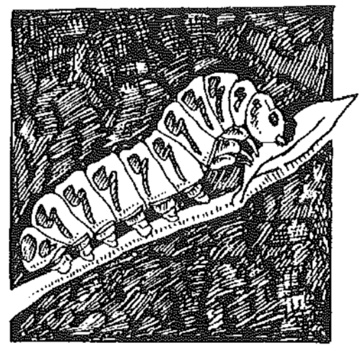
4. Identify the shapes of two-dimensional cross-sections of three- dimensional objects, and identify three-dimensional objects generated by rotations of two-dimensional objects.

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects.
2. Apply concepts of density based on area and volume in modeling situations.

T-51. At 2:00 PM, Deion observed a caterpillar crawling up a barn wall. He estimated his distance to the wall as 8 feet and his angle of sight up to the caterpillar as 10°.



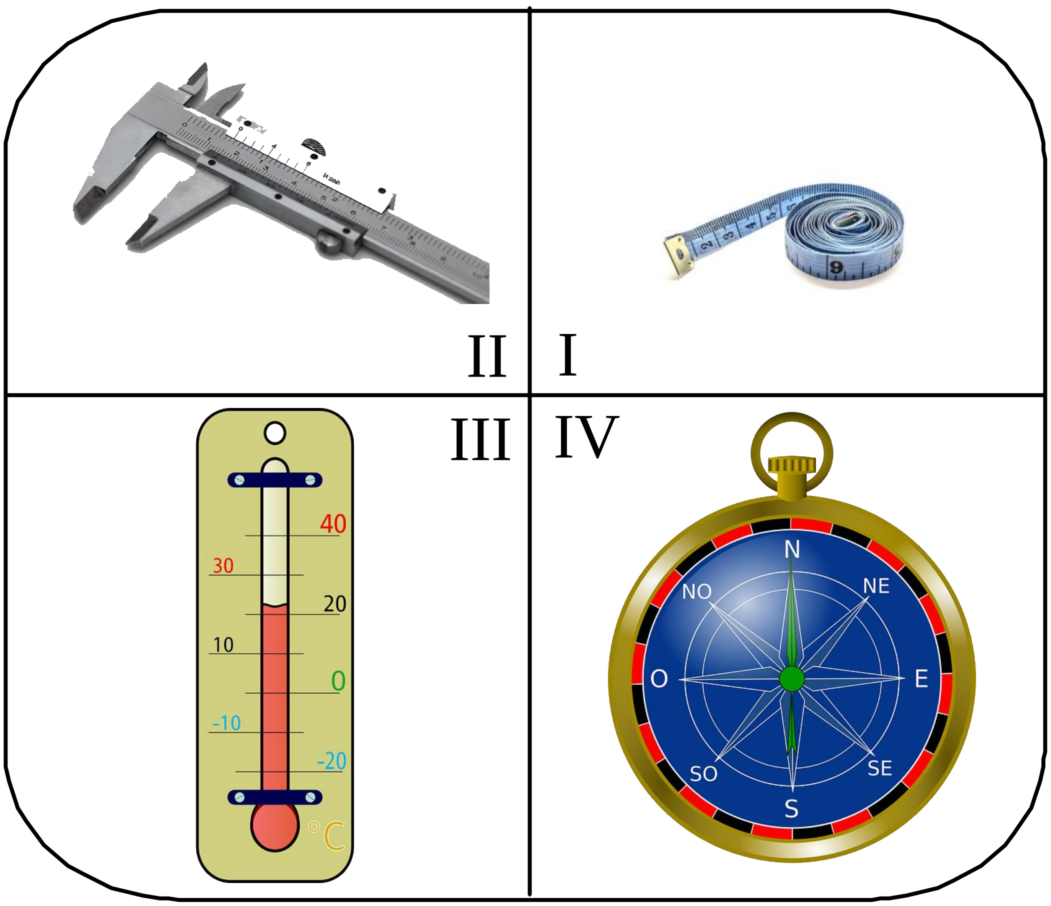
a) If Deion's eyes are about 6 feet above the floor, about how high is the caterpillar on the wall at 2:00?

b) At 2:05 the caterpillar has moved up the wall and Deion's angle of sight is now 25°. How far has the caterpillar crawled in the 5 minutes?

c) If the caterpillar is 15 feet up the wall at 2:17, at what angle is Deion observing the caterpillar?

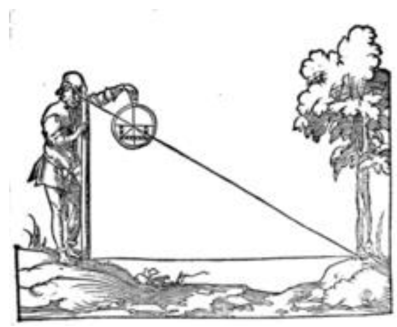
d) If Yvonne comes over and asks Deion to get a ladder and rescue the caterpillar, about how long must the ladder be if it is set at a 70° angle with the ground? Presume that the caterpillar has not moved since 2:17.

Which One Doesn't Belong?

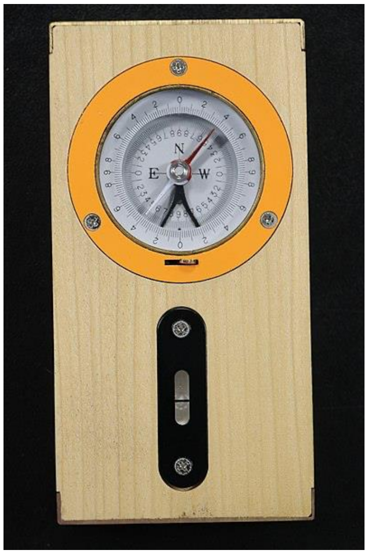


Clinometer used by foresters

wooden clinometer

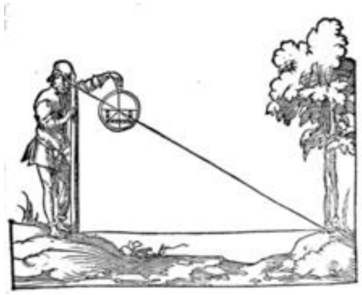


Woodcut from *Elucidatio fabricae ususque astrolabii* (1553) by Johannes Stöffler showing the use of an astrolabe or inclinometer to measure the distance across a stream.



Clinometer used by foresters

wooden clinometer



Woodcut from Elucidatio fabricae ususque astrolabii (1553) by Johannes Stöffler showing the use of an astrolabe or inclinometer to measure the distance across a stream.

Student Conservation Association core member Brett Murphy looks up into the canopy of hardwoods on Wayne National Forest using a clinometer measure tree highth. Two teams of SCA members worked on a "Recovery Act" project gathering FIREMON data for the USDA Forest Service.

U.S. Air Force Maj. Ryan Schenk, foreground, with Air Mobility Command assigned to the Army's 4th Brigade Combat Team, 10th Mountain Division, demonstrates to Service members with the Farah Provincial Reconstruction Team (PRT) how use a clinometer to measure glide slope obstructions near the Farah, Afghanistan, aircraft landing zone July 30, 2013, during landing zone safety officer training. Farah PRT's mission was to train, advise and assist Afghan government leaders at the municipal, district and provincial levels in Farah province.

Wendell Jones, NRCS District Conservationist, measures slope on farm near Iowa City, IA. [Slide 97CS3062]

U.S. Air Force Maj. Ryan Schenk, foreground, with Air Mobility Command assigned to the Army's 4th Brigade Combat Team, 10th Mountain Division, demonstrates to Service members with the Farah Provincial Reconstruction Team (PRT) how use a clinometer to measure glide slope obstructions near the Farah, Afghanistan, aircraft landing zone July 30, 2013, during landing zone safety officer training. Farah PRT's mission was to train, advise and assist Afghan government leaders at the municipal, district and provincial levels in Farah province.

Student Conservation Association core member Brett Murphy looks up into the canopy of hardwoods on Wayne National Forest using a clinometer to measure tree height. Two teams of SCA members worked on a "Recovery Act" project gathering FIREMON data for the USDA Forest Service.

DAY 7 **T-75 through T-83**

CLINOMETER CONSTRUCTION

The next two days include an outdoor activity with students making clinometers and then using them. This activity is very powerful for helping students understand what is meant by "angle of elevation" and "angle of depression." Each day has a set of problems to continue practicing. You can also do some problems that you may have skipped. The objective of the first day is to complete the clinometer. This can be done in less than half an hour if you have all the materials ready and walk around the room monitoring progress and stapling the strings. There are two more problems to do in class today.

In the following problem, each <u>pair</u> of students makes a clinometer to measure angles. They will need paper copies of protractors from the resource packet in order to make their clinometers. They will also need straws, string, staplers, a 4" x 6" index card, glue, tape, and something to tie on as a weight (such as 1/4" washers).

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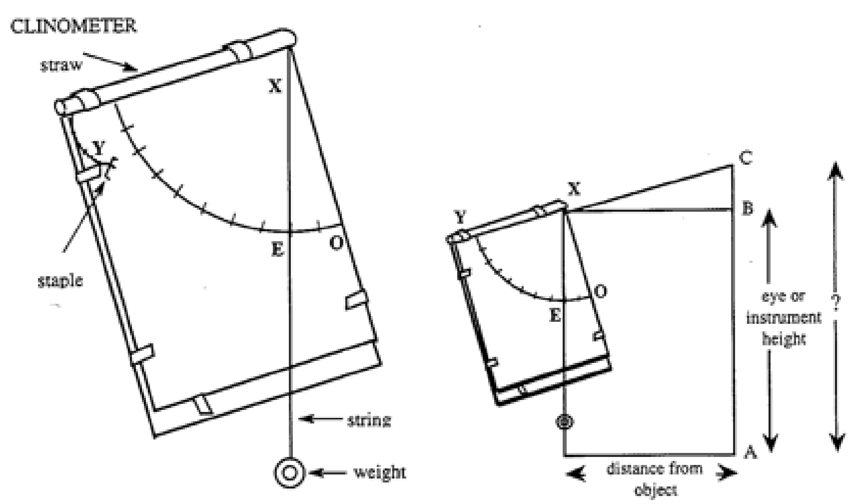
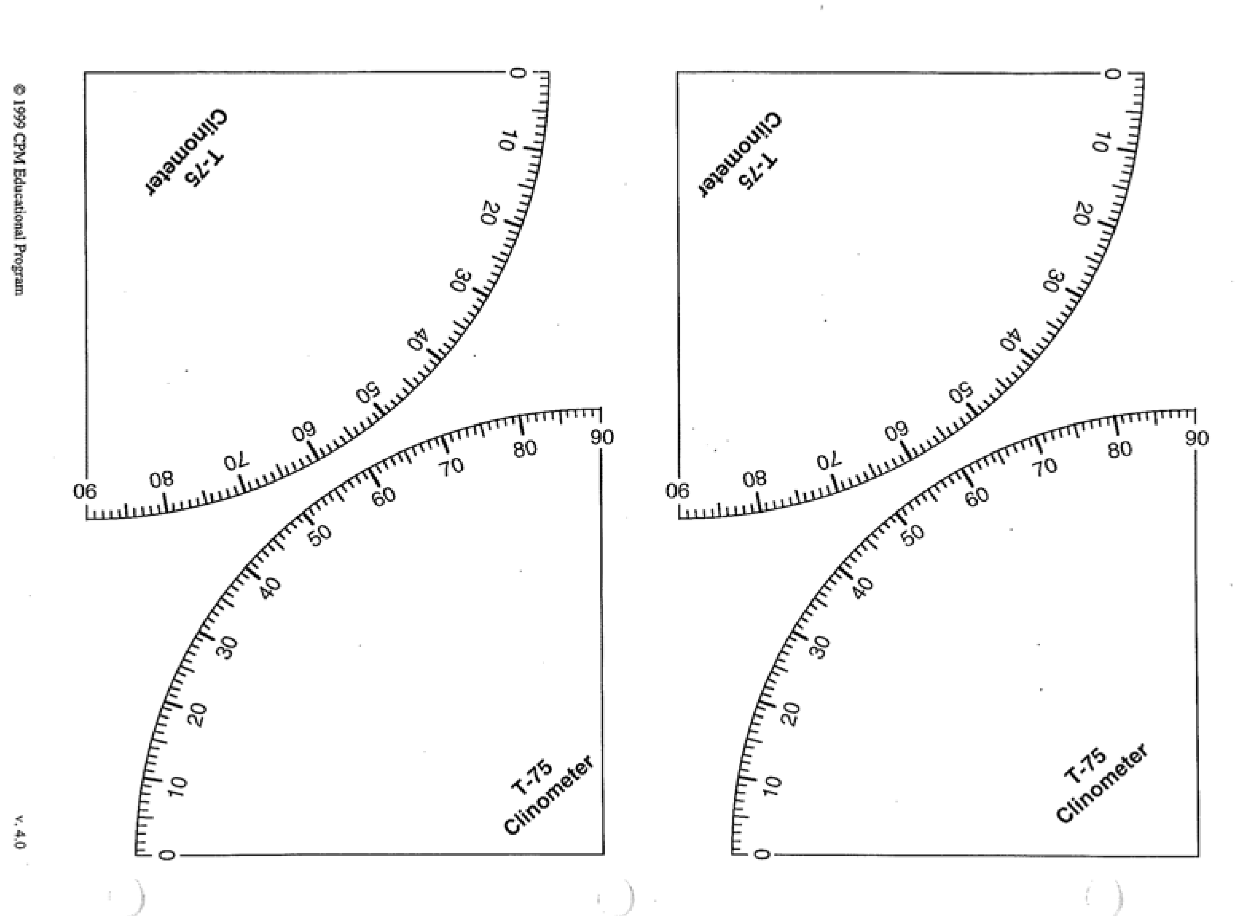
T-75. **HOW TO MAKE A CLINOMETER:** Working in pairs, cut out and tape or glue a protractor scale to an index card as shown. **Attach the top edge $\overline{XY}$ along the top edge of the card.** Tape on a soda straw as shown. Put the string into the straw at X, pull it through the straw, and staple it to the card near Y. Tie a weight to the other end of the string so that it will hang vertically a little below the bottom of the card.

When using the clinometer, you should stand at a convenient distance from an object whose height you wish to measure. Sight the top of the object through the straw. Mark the point E where the string intersects the protractor scale. Your partner can help you with this. Carefully study the diagrams which follow so that you will be ready to use your clinometer tomorrow.



* The Clinometer activity is based on a presentation given by Micheal Palmer at the 1987 Invitational Summer Institute of the Northern California Mathematics Project.


T-75
Clinometer
T-75
Clinometer

Height Challenge Project

We have studied Right Triangle Trigonometry and used it to find missing sides and angles of right triangles from given problems and in application. This project is to find heights of various objects or sites on our school's campus. You will work with a team to create and solve a height challenge. Each student should have the permission slip signed and returned by the second day of the project.

1. With your team, select an object or site to measure with the drone. The height must be greater than or equal to 7 feet/2.13 meters and there must be a safe way to measure it with a drone (i.e., there must be unobstructed access). When surveying with your team, select more than one object/site, incase another team selects the same object. If more than one team has selected the same object/site, the teacher will fairly decide which team can select it as their challenge. Report your object choice to the teacher on the google form.
2. Once your object/site has been approved, your team may follow the guidelines to measuring the height with the drone. These guidelines will depend on how the school administration allows drone usage. Record the actual height on the appropriate google form.
3. With your team, prepare the challenge for the receiving team, explaining the object or site they are to measure in detail.
4. Exchange height challenges with the other teams.
5. Calculate the height of your challenge, making sure each team member measures their own horizontal distance from the object and angle of elevation.
6. Complete your calculating height challenge worksheet.
7. After the receiving team has completed the challenge, check their average calculated height and find the percent error.
8. $percent\ error = \frac{|actual\ height - calculated\ height|}{actual\ height} * 100$
9. Complete the project reflection questions.

Height Challenge Rubric

Student______________________________________ Per.________ Team____________

	Task	Possible Points	Earned Points	Notes
	Challenger:			
1	Height challenge object/site selected	10		

2	Height challenge object/site measured accurately with drone	20		
3	Height challenge percent error calculated accurately	10		
	Calculator:			
4	Clinometer constructed accurately	15		
5	Height challenge object/site measurements made accurately (angle of elevation and horizontal distance)	20		
6	Height challenge object/site calculated accurately	10		
7	**Percent Error Points:**			
	0-5%	15		
	6-10%	10		
	11-25%	5		
	26-50%	2		
8	Completed reflection questions thoughtfully	5		
	Total Points	100		

Height Challenge Project
Team Challenge Form

Class:______________________________ Per.________ Date:____________

Challenging Team Members:____

Geographic Location of the object/site:____

____

Detailed description of the object/site:____

____

Receiving Team ______________

Receiving Member 1 – Name______________________________ Eye Height:________

Horizontal Distance from object/site:______________ Angle of Elevation:____________

Calculated height of object/site:________________

Receiving Member 2 – Name______________________________ Eye Height:________

Horizontal Distance from object/site: ______________ Angle of Elevation:____________

Calculated height of object/site:________________

Receiving Member 3 – Name______________________________ Eye Height:________

Horizontal Distance from object/site:______________ Angle of Elevation:____________

Calculated height of object/site:________________

Receiving Member 4 – Name______________________________ Eye Height:________

Horizontal Distance from object/site:______________ Angle of Elevation:____________

Calculated height of object/site:________________

Average of calculated heights of object/site______________

Height Challenge Reflection

For this project you have:

- Worked with your team to select an object/site to measure.
- Made measurements with a drone, tape measure and clinometer.
- Built a clinometer.
- Calculated height with trigonometry.
- Calculated percent error.

Answer the following questions with as much detail as possible.

1. What task/aspect of this project did you enjoy most?

2. What skills did you use that you think will be applicable in your future?

3. Why do you think applying math skills to real life is an important part of learning?

4. Did you enjoy using drone technology? In what other ways, besides personal entertainment, do you think drones could be used?

5. Do you think working with a team helped you with this project? If so, how? If not, why do you think working by yourself would have been better?

6. What changes would you suggest be made to improve this project?

How Big is Our School?

Measurement Project

We have studied area and volume and used our knowledge to find capacity measures for various polygons and polyhedral. You have also walked these hallowed marble halls and to and from our campus over 200 times. This project will ask you to combine your academic knowledge to the specifics of our school. You will work with a partner or your team to use drone photographs to find the area and volume of rooms or sites in our school and on our campus.

1. Work with the class and the drone(s) in obtaining aerial photographs of the school and measurements for various heights (1st floor, 2nd floor, roof, etc.), widths and lengths. Gather measurements for the entire school, but also particular measurements for wings or other parts of the building or the campus.
2. With your team, decide the part of the school or campus, inside or out, you will choose to measure capacity. Select more than one possible area in case there is more than one team who wants the same part. If two teams want the same site, the teacher will decide fairly between the teams.
3. Find the area and volume (if applicable) for your part of the building. Take into account the shape(s) and dimensions from the drone photograph and measurements. Be as accurate as possible (i.e., does the room have a curved wall?). Use the agreed upon units of measure (cm, in, feet, meters, etc.).
4. Now that your team has found the measure of capacity for your site, you must choose a specific object, inanimate, hypothetical, or alive, to use to fill the specific site. For example, if you have selected and found the area of the football field, you could ask: "How many football players, lined up side to side and head to toe would it take to completely cover the field?" If you selected and found the length of the driveway leading to and extending through the parking lot, you could ask: "How many McDonalds french fries, laid end to end, would it take to reach the entire length of the driveway and parking lot?" If you selected and found the volume of gymnasium, you could ask: "How many Indian elephants, stacked side by side from floor to ceiling, would it take to fill the gymnasium?" Have fun with this part of the project, but keep it clean and relevant.
5. Hand your question and answer into the teacher, who will pass the questions to other teams. Also include the actual capacity in the agreed upon unit of measure.
6. With your team, solve the question you received and hand the answer into the teacher.

How Big is Our School?

Measurement Project Grading Rubric

Students____ Per_________ Team_______

	Task	**Possible Points**	**Earned Points**	**Notes**
1	Site selected on time	10		
2	Accurate measurements acquired	15		
3	Accurate calculations of capacity made	20		
4	Fermi-type question posed with correct answer calculated and given	25		
5	Posed Fermi-type question calculated accurately	30		
	Total Points	**100**		