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The Mariner's Quadrant: Teaching Keystone Concepts via a Historical Engineering Tool

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Abstract

Fundamental concepts in mechanical engineering curriculums are the foundation for building advanced education topics. Topics such as proper empirical data collection and evaluation methods, variable sensitivity, uncertainty, and verification vs validation are essential to the engineer's toolkit. However, it can be difficult to impart the criticality of such topics to undergraduate students in the early years, especially to Freshman students overwhelmed with new experiences and responsibilities. Even students who successfully learn these skills will quickly forget them, inhibiting the synthesis of those skills with future lessons.
An entertaining, hands-on laboratory activity centered on the quadrant tool from antiquity can be effective in teaching those crucial skills. The Mariner’s Quadrant is a historical nautical tool that navigators used to measure celestial body altitude, the forerunner to modern sextants, surveying equipment and remote measurement devices. There are many variants of the quadrants throughout history for different purposes, including measuring planetary movements, aiming cannons during battle, or surveying the land.

This paper presents a customizable Quadrant Lab Activity and illustrates how students learn a variety of critical engineering concepts through experiential learning. Students assemble the quadrant tool and then venture outdoor to determine the height of a tall structure through remote measurement. Upon return to the classroom, the students compile their data into a large set for analysis. Through this activity, students begin learning best practices in data collection and assessment and see the impact of limited precision data first-hand. Through data assessment, variable sensitivity and uncertainty are evaluated, and students must identify the sources of uncertainty in the physical world. Once the activity results have been fully analyzed and a solution is obtained, the students must both verify and validate the solution. These concepts are memorable due to the engaging nature of the activity and produce an appreciation for historical engineering methods as a resource. The analogue nature of the tool appears to improve the understanding and synthesis of the lesson, as opposed to memorizing a procedure.

This paper provides a valuable and customizable lab activity for educators and curriculum developers seeking to improve Freshman/Sophomore mechanical engineering lab courses. The Quadrant Activity supports ABET learning outcomes 1 (solve complex engineering problems), 4 (recognize ethical responsibility/make informed judgements), 5 (ability to function on a team), 6 (develop and conduct appropriate experimentation), and 7 (ability to acquire and apply new knowledge). The efficacy of this lab activity is shown through qualitative and quantitative assessment, via instructor observation and a pre- and post-activity assessment.

1. Introduction

Empirical data collection, evaluation methods, variable sensitivity, uncertainty quantification, and the processes of verification/validation are important data skills for an engineer to have, but they are not always emphasized in the undergraduate mechanical engineering curriculum. To bridge the gap, this paper presents a hands-on laboratory activity centered on the use of a relatively simple historical engineering tool: the Mariner's Quadrant. This activity not only introduces students to key engineering principles, but does so in a way that is memorable and engaging. While students enjoy examples of technology that showcase current industries they aspire to, the response to the Mariner's Quadrant has been exceedingly positive. The quadrant, a precursor to sextants and surveying instruments, offers students a tactile, analog experience that accomplishes modern educational objectives.

Through constructing and using the quadrant, students gain direct exposure to the principles of remote measurement, data collection, and data analysis. They also experience the tangible impact of variable sensitivity and uncertainty in real-world measurements that standard lecture or computer-based simulations may not achieve.

The quadrant activity leverages experiential learning to enhance student understanding of essential skills and builds their confidence in applying them. Furthermore, the activity aligns closely with ABET student outcomes 1 and 4-7. The following sections of this paper will outline the design of the activity, its method of assessment, and its results, illustrating how this approach can be integrated into existing mechanical engineering lab courses to improve learning outcomes.

2. Historical context and pedagogical significance

2.1 The Mariner's Quadrant

The quadrant tool has its roots in antiquity, and has been remade in varying forms for many different purposes throughout history. The Mariner's Quadrant variant (Figure 1) was designed to aid sailors in navigation, and was used to determine a ship's latitude by measuring the angle between the horizon and the North Star [2,3]. Other variants of the tool were employed for many purposes, such as the Astronomer's quadrant that measured planetary movements, or the Gunner's Quadrant that artillery officers used to sight cannons and measure the height of battle fortifications [3]. The Islamic Horary Quadrant had both astrolabic and sinical markings that aided in the determination of time [4,5]. There were even quadrants for surveying land for construction, or determining the number of bricks required to repair walls [3].

To utilize the Mariner's Quadrant, a sailor would look through the sights at the target to be measured, as demonstrated in Figure 2. A line with a plumb bob or similar weight would reveal the angle between the sailor's sightline and the target. Many quadrants were even engraved with a "shadow square", which is a graphical method used to determine the tangent or cotangent of an angle of interest and other basic surveying measurements [2]. A small sliding bead on the weighted line allowed for variable use of the shadow square. Figure 3 shows a fairly accurate quadrant reproduction used for lecture demonstrations, which was made from walnut, ink on aged parchment, and a brass plumb bob hung from waxed Irish Linen twine.

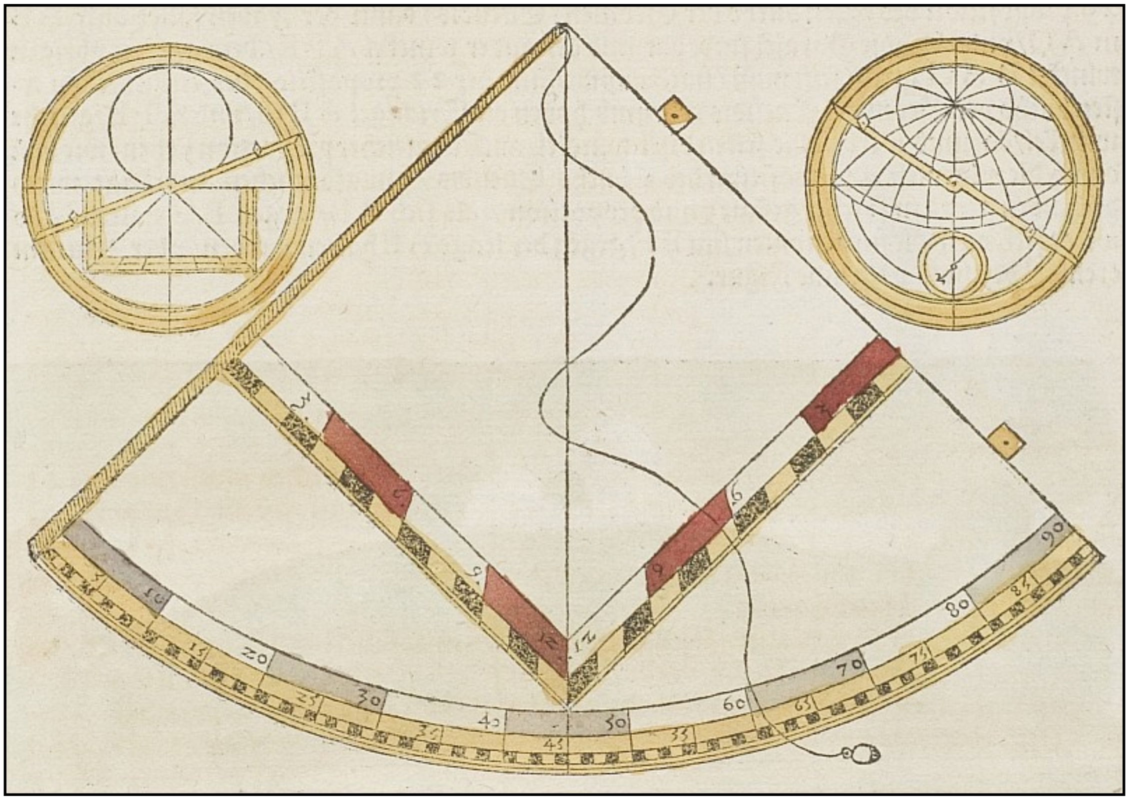

Figure 1: Sketch of a Quadrant Tool. Image Artist: Petrejus, Johann (Drucker), 1547 [1].

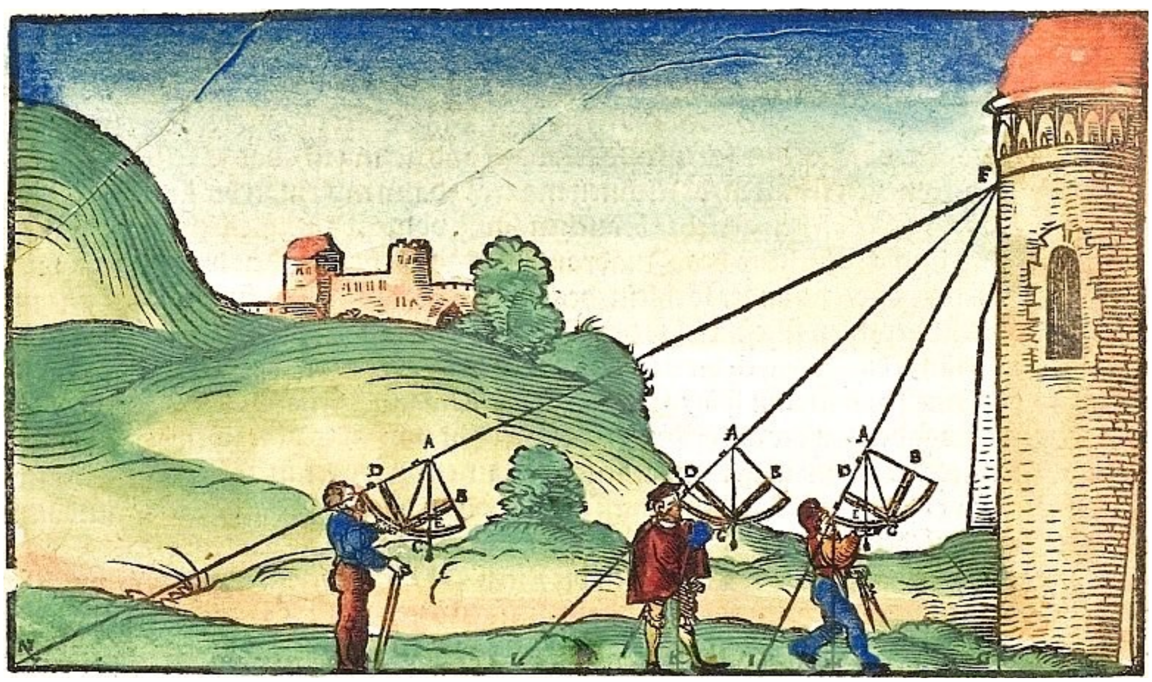

Figure 2: Measuring the height of a building using a quadrant. Image Artist: Petrejus, Johann (Drucker), 1547. [6]

Figure 3: Historical reproduction of a quadrant.

2.2 Benefits of analog tools in education

The tactile and visual nature of analog tools like the quadrant offers unique pedagogical advantages. Hands-on activities engage students physically and cognitively, making abstract concepts more tangible. Educational enrichment is critical, especially for Freshman and Sophomore students who often respond better to more guided support to master foundational engineering skills [7]. Further, measurably noted benefits include an improvement in creative problem solving [8] and increased undergraduate student retention in engineering programs from implementing experiential hands-on approaches in Freshman year classes [9].

Moreover, analog tools foster an appreciation for the iterative and often imprecise nature of engineering problem-solving. Students encounter the challenges of variability in outdoor conditions, human error, and tool limitations, allowing them to explore real-world implications. These experiences are difficult to replicate with digital tools, where outputs are often presented as black-box solutions, detaching students from the underlying processes and disguising technical limitations.

2.3 Integration into curriculum

Incorporating historical tools into the engineering curriculum provides a unique opportunity to blend technical skills with historical and contextual understanding. The quadrant activity complements traditional lab exercises by introducing an interdisciplinary approach, connecting mathematics, physics, and engineering design. Additionally, its analog nature offers an engaging alternative to modern, often screen-intensive, instructional methods.

For example, when students physically measure angles and calculate heights using the Mariner's Quadrant, they gain a concrete understanding of concepts such as measurement uncertainty and variable sensitivity. As an analog tool, the quadrant relies on fundamental principles of trigonometry and geometry, providing users with direct, hands-on experience in applying mathematical concepts to solve real-world problems. Unlike modern digital instruments, which often obscure the underlying principles, the quadrant's simplicity and transparency make it an ideal teaching tool. Its historical significance adds an element of curiosity and context, allowing students to connect engineering principles with their historical applications.

Some museums and other organizations have developed small-scale projects targeting k-12 students that make and use paper quadrants as an interactive geometry and history lesson [10-13]. The Mariner's Quadrant activity presents in this paper has been enhanced with engineering principles and data collection methodology to elevate the complexity for university undergraduate curriculums. It is particularly well-suited for freshman and sophomore-level courses, where students benefit from activities that balance technical rigor with accessibility. The historical dimension of the tool enriches the educational experience, demonstrating how engineering principles have evolved while underscoring their timeless relevance.

3. Assessment results

3.1 Activity Structure and General Procedure

The Quadrant Activity is comprised of three phases:

1. Assembly Phase
2. Data Collection Phase
3. Data Analysis phase

The Assembly Phase is just as it sounds, and students receive the quadrant, weight and suspension material (wire or thread/twine), and must assemble them into a functional tool. To keep the lab activity economical, the body of the quadrant was 3D-printed out of PLA filament with low density settings, the weight was a heavy washer, and the "string" was either twine or a straightened paperclip. Figure 4 provides an example of the assembled student Mariner's Quadrant. Additional equipment needed can include optical rangefinder, long tape measure, or as simple as counting steps/paces.

The body of the quadrant could also be laser cut (Figure 4) if a 3D-printer is not available, but peep sights will need to be fabricated and assembled separately. This is another source of uncertainty to any measurements taken with the tool, as good alignment of the sights is crucial. The 3D-printed version has the benefit of the sights built in with the body, so misalignment is minimized.

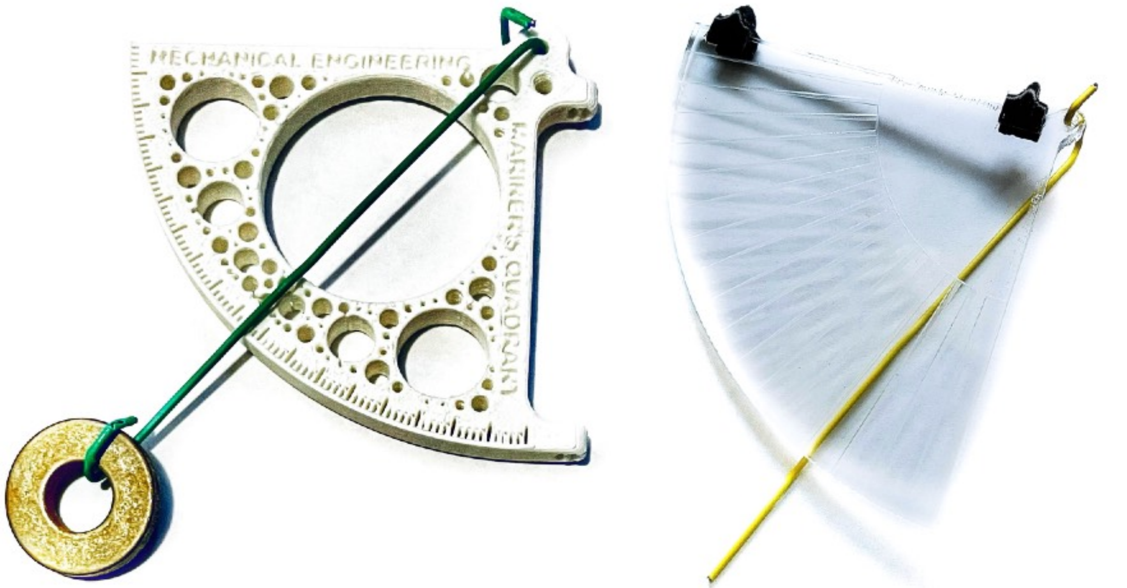

Figure 4: The Mariner's Quadrant 3D-printed with window cutouts for economical material usage (left), and a laser cut alternative (right).

For the Data Collection Phase, the students ventured forth out of the classroom to determine the height of the campus clocktower. The data collection is completed as a team, but as multiple data points are needed for a full set, each individual student will get first-hand experience. Student teams must then take 5 to 10 angle measurements that span a range of distances from the base of the clocktower. Figure 5 presents a simple schematic of the data collection considerations and variables, such as eye height, distance from the clocktower base, and the measured angle. The student teams will share their data (comprised of eye height, distance from the tower, and the measured quadrant angle) with the class, so that all students have access to the total crowdsourced dataset.

Once the data has been crowdsourced, the Data Analysis Phase commences. The recorded variables all combine to form a simple right triangle (Figure 5), and the angle measured from the quadrant tool can then be utilized to calculate the height of the clocktower via basic trigonometry:

Eq.1 $$h_{tower} = h_{eyes} + \left(D * tan\theta\right)$$

Where h_{tower} is the height of the target, h_{eyes} is the distance from the ground to the operator's eyes, and D is the distance between the operator and the base of the target.

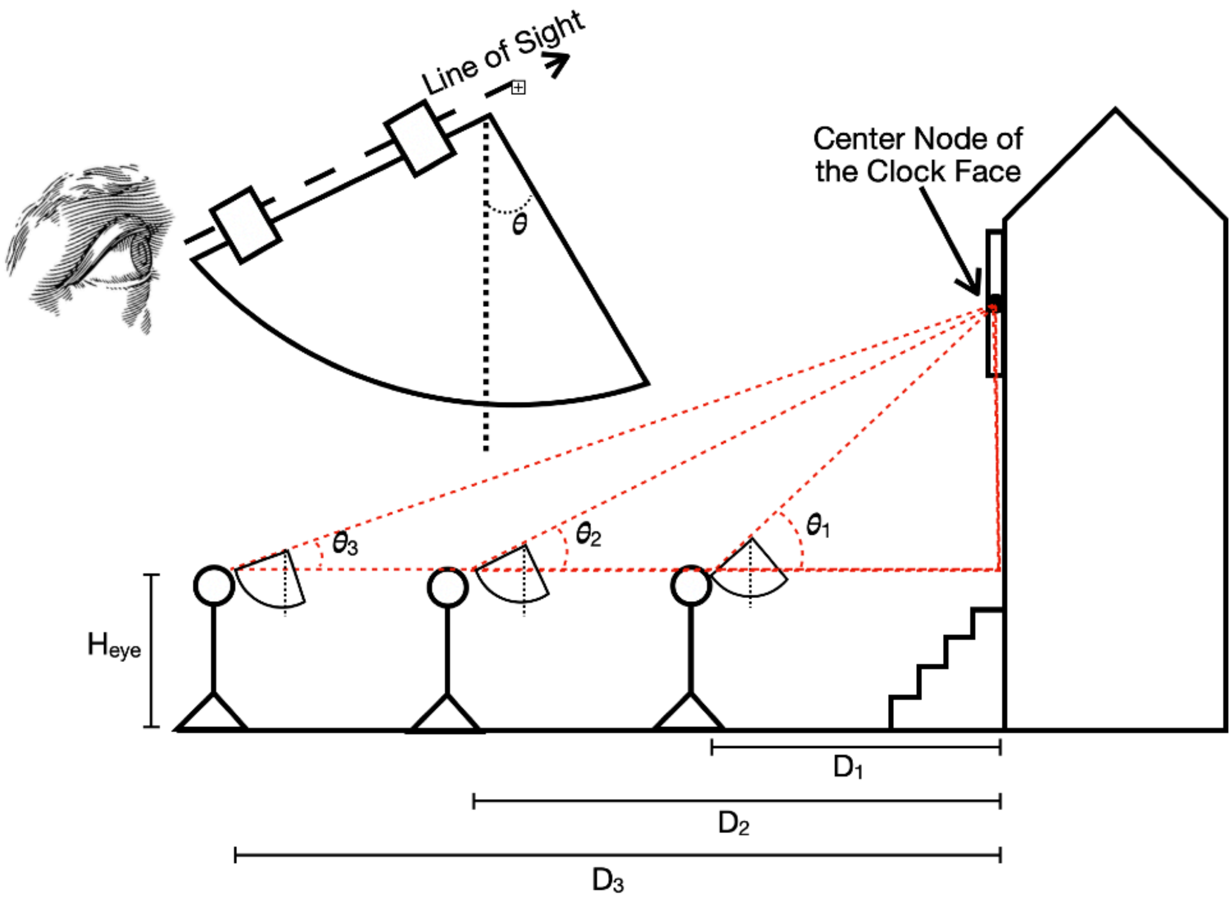

Figure 5: General schematic of angle measurements from a range of distances.

Sample data from the activity can be viewed in Figure 6. Students learn and utilize a number of techniques to determine the height of the clocktower and assess its validity:

- Scatterplot construction and formatting
- Trend line construction and r^2 value
- Visually identifying data scatter
- Identifying sources of uncertainty
- Recognizing non-linear variable sensitivity
- Calculating standard deviation.

As seen in the sample scatterplots, the calculated height of the clocktower is relativity consistent except when measurements are taken at close distances to the tower base. Students must think critically about what the data indicates about variable sensitivity and discuss what drives the phenomenon. Students must also make engineering decisions about which data to include when determining the clocktower height they will ultimately report, and what the uncertainty is for that reported value.

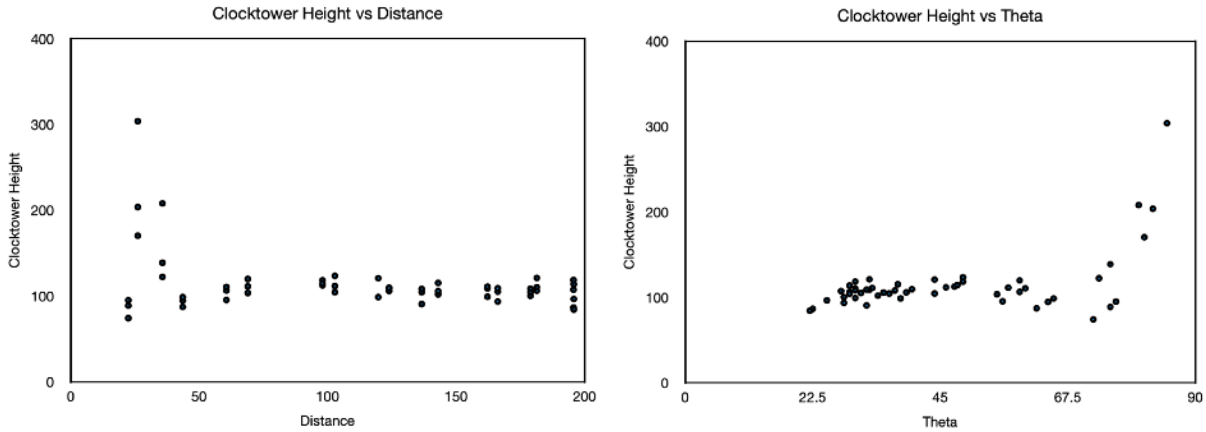

Figure 6: Scatterplot of sample activity data comparing the calculated clocktower height to the distance to the base (left) and the calculated clocktower height to the measured angle (right).

Observations and Recommendations

- Students enjoy taking the lesson out of the classroom, so assigning a beloved campus feature as the target to measure will increase their positive perception of the lesson. For ease, it is best to teach them how to use the tool and to provide a schematic with the tool's proper orientation on their instructional sheet before sending them afield.
- When crowdsourcing the data from multiple student teams, it is helpful to provide them with a labeled data table file for them to use for consistency. When the individual teams submit their data to the instructor or Teaching Assistant, it is much simpler to compile the data when arranged with consistent format and units.

3.2 Customization opportunities

There are many ways to scale/customize the Mariner's Quadrant activity to suit any curriculum's needs.

To scale down the activity, the students do not necessarily need to leave the classroom. While there is a higher engagement when students get to leave the classroom and visit an interesting feature on campus, it is not always feasible. Simply set up a small dot target at the highest point on a wall or in a hallway for the students to measure. The activity posed in this paper fabricated a quadrant for each student to keep (CAD model shown in Figure 7), which was positively perceived, but this too is not always feasible. Having one quadrant pre-made for each team's temporary use can reduce cost and labor.

There is a wonderful opportunity to expand this activity by adding a demonstration of modern surveying equipment. The students would then be able to compare their data/results to that of the modern equipment, and critically assess how the historical tool was developed into its modern counterpart. This is also a wonderful way to introduce the bridge between analogue tools to the operation and fundamental principles of electronic instruments.

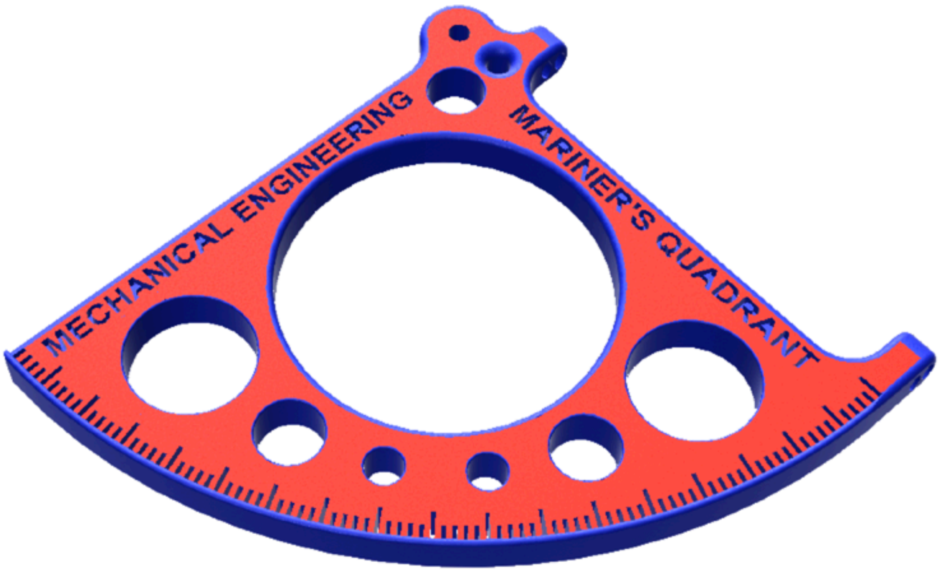

Figure 7: CAD model of Mariner's Quadrant body for 3D-printing. Symmetric window cutouts for style, minimizing material consumption and weight reduction.

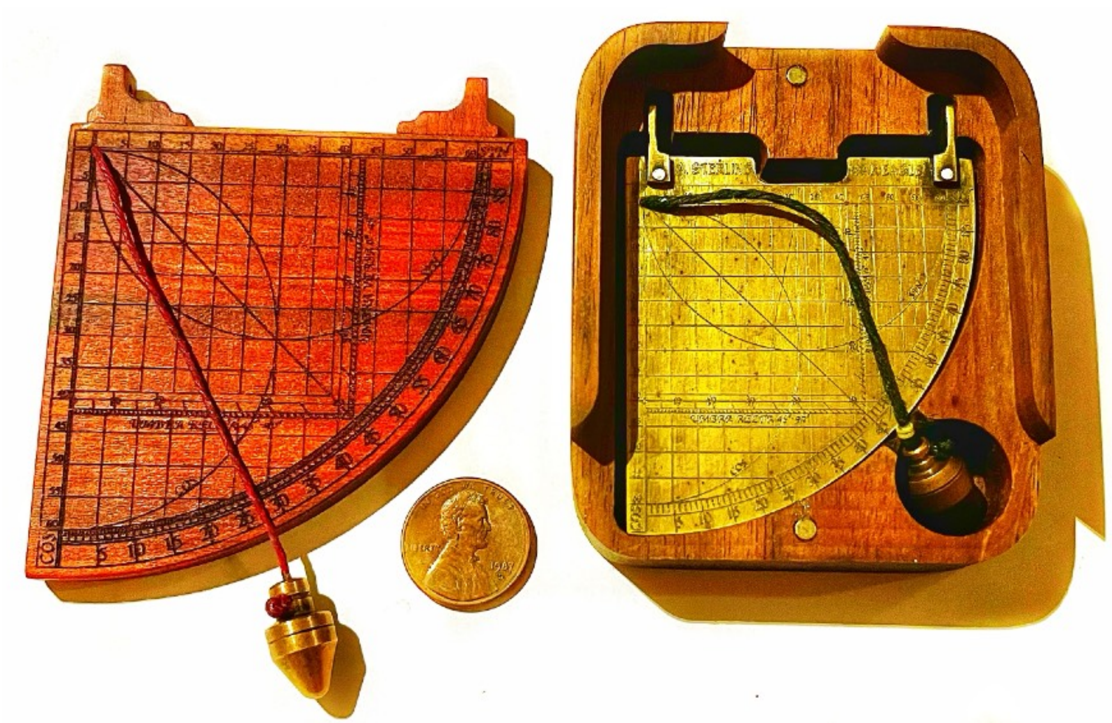

Figure 8: Quadrant variants fabricated from laser-engraved tulip wood (left) and CNC machined brass with riveted sights in a walnut box (right).

If this activity is implemented during Sophomore or even Junior year, it could be expanded into a project paired with a fabrication/machining element (example shown in Figure 8). Rather than be provided with the quadrant, the students can be tasked with fabricating the quadrant themselves (or even a simplified sextant with vernier scale) via a tutorial, or even designing key aspects themselves. Then, not only could the crowdsourced bulk data be analyzed, but the data from different quadrant designs could be compared. Teams might then observe changes in the data obtained from quadrants of different sizes, different measurement scales, and fabrication tolerancing decisions. Optimization discussions would then have strong basis in quantitative assessment as well as qualitative user ergonomics. As a final note, allowing each student to keep their own creations generates a great deal of pride in their accomplishment and increases the positive perception of the experience for both students and parents.

4. Impact assessment of the quadrant activity

4.1 Pre- and post-activity quiz results

A pre-activity conceptual quiz was administered to the students after the content lecture but before the quadrant activity. The correct answers were not yet revealed. The results of the pre-activity conceptual quiz provide insight into how much knowledge of the critical topics the students retain from the traditional classroom introduction.

After the quadrant activity was completed by the students, the same conceptual quiz was given again. The post-activity conceptual quiz was administered approximately two weeks after the pre-activity conceptual quiz. The correct answers were revealed afterwards for educational purposes in the class. Comparing the post-activity results with the pre-activity results measure the efficacy of the quadrant activity to improve students' knowledge retention and understanding of critical topics.

While the quadrant activity has been part of the curriculum for approximately 2 years, the conceptual quiz data is collected from 2 representative semesters (Fall 2024 & Spring 2025). The number of students who participated was N=333. No control sections were utilized to avoid excluding any students from the educational benefits of the quiz. The pre- and post-activity quiz (available in Appendix B) was comprised of 5 multiple-choice questions and 1 calculation question focused on the following concepts:

1. Standard deviation (population vs sample set).
2. Variable sensitivity.
3. Linear, non-linear, threshold variable sensitivity.
4. r^2 values (trend line fit assessment).
5. Verification vs Validation.
6. Uncertainty.

The pre-activity results (Figure 9) are typical for lecture delivery methods observed in previous semesters (a bulk average of 45.3% across topics), even in earlier semesters prior to the quadrant activity becoming a staple to the course curriculum. The lowest scoring topic in the pre-activity quiz was that of uncertainty, which was also the only calculation style question.

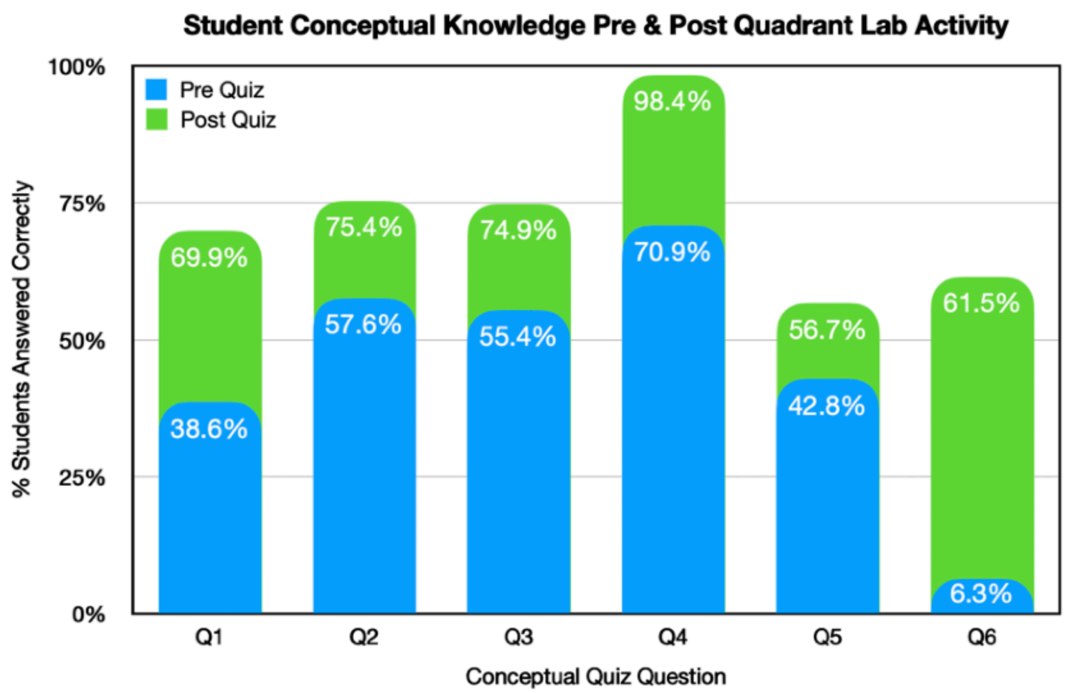

Figure 9: Comparison of pre- and post- activity conceptual quiz results.

As can be seen in the graph, there was improvement in all topics (and bulk average of 72.8% across topics), though some saw greater improvement than others. Notably, the topics of standard deviation, trend line fit, and uncertainty saw the most improvement, the percent success increasing by ~28-55%. These three topics are the primary calculations performed during the Data Analysis Phase of the quadrant activity, which may be why these topics were most improved upon. Direct measurements and calculations provide the best connection with the material.

The other three questions saw less improvement in the topics of variable sensitivity and its tertiary concepts, and the difference between verification and validation. The percent success increased by ~14-20%. These topics tend to be more abstract to Freshman students on first introduction, and require multiple exposures to material before they can effectively synthesize and apply the concepts to other scenarios. The conceptual quiz questions asked students to identify the correct statement for new scenarios, and two of the multiple choice answers had only a subtle difference. For example, question 3 is presented below:

> *Scenario*: A car's steering system is designed to be more sensitive to small steering movements at low speeds but less sensitive at high speeds. This is an example of:
>
> a) Variable sensitivity with a linear relationship to operating conditions.
> b) Variable sensitivity based on operating conditions.
> c) Threshold insensitivity.
> d) Feedback control insensitivity.

The correct answer is option b, but option a is a plausible distractor. In the post-activity quiz, approximately ~91% of students answered with either option a or b, and only ~9% were far off the mark. This pattern is mirrored on the other questions with lower improvement rates. However, the incorrect answers on the pre-activity quiz did not see this optimistic trend.

An overall assessment of the results was conducted via Welch's t-test (two-tailed, unequal variance), using the results of each question as a data point in the set. The resulting p-value was 0.0320, indicating a significant change due to the educational activity. In conclusion, there is significant improvement in the more practical, directly applicable skills, and a positive trend overall. While the percent success saw less improvement for the more abstract concepts, there was clear improvement in the students' general understanding. This is an important foundation that better situates the students for future comprehension once they gain more experience.

4.2 Student Perception

Students are offered a chance to provide end-of-semester anonymous reviews. The class routinely receives positive reviews overall, but students often cite the quadrant activity as one of their favorite lab activities.

One memorable review called the quadrant activity the best lab because it was like "old-school surveying," and many others have provided feedback along the same lines across multiple semesters. The historical link appears to have successfully sparked the students' curiosity, and the data collection phase of the activity taking place outside of the classroom has added to the students' positive perception of the class.

4.3 Alignment with ABET student outcomes

The quadrant activity aligns closely with ABET student outcomes 1, 4, 5, 6, and 7. Outcome 1 (solving complex engineering problems by applying engineering principles) is achieved through the students applying fundamental trigonometry to a real-world situation with more than the basic variables. They must figure out which variables must be accounted for and how to correctly account for them, such as measuring their "eye height" instead of the their total height, sloping ground, string or wire thickness or accounting for distance measurement obstructions, such as stairs in front of the clocktower. These details are simple on paper, but easily overlooked in the field.

Outcome 4 (recognizing ethical and professional responsibilities and making informed judgments) and Outcome 5 (Functioning effectively on a team) are met through the activity aspect of crowdsourcing data from the entire class. Students teams tended to work harder and take more care when collecting their data when they realized other student teams would be relying on the quality of each other's work. The students recognized the importance of clarity and accuracy when producing technical data. This lesson can be further emphasized with a critical thinking question at the end of the activity.

Outcome 6 (Developing and conducting appropriate experimentation, analyzing data, and drawing conclusions) is thoroughly achieved as the students step through and improve upon the data collection methodology, and analyzing the crowdsourced dataset to determine the height of the clocktower and the uncertainties. The students recognize the importance of rigorous data collection standards when they see the great impact minor offsets in the field can have on the calculated results.

Outcome 7 (Acquiring and applying new knowledge using appropriate learning strategies) is activity accomplished through the different technical skills learned and applied in the quadrant activity. The students are introduced to a new measurement tool, they practice new data collection strategies on a new real-world challenge, and they learn new Excel skills to graph data and program calculations for analysis.

5. Conclusions

5.1 Summary conclusions

The Mariner's Quadrant Activity presented in this paper supports engineering education by providing a tactile and engaging learning experience that integrates theoretical knowledge, practical skills, and teamwork. Additionally, it has proved to be educational for foundational topics critical to engineering and other technical fields. The activity is comprised of 3 stages:

1. The Assembly Phase introduces students to the Mariner's Quadrant as a historical, analogue tool and teaches them how to use it. This phase of the activity supports ABET Student Learning Outcomes 1 (identify, formulate, and solve complex engineering problems) and 7 (acquire and apply new knowledge).
2. The Data Collection Phase allows students to explore campus and collect field data that will become part of a crowdsourced class-wide dataset. They are exposed to ethical considerations of responsible data collection methodology, standards, and publication. This phase of the activity supports ABET Student Learning Outcomes 4 (ability to recognize ethical and professional responsibilities), 5 (function effectively on a team), 6 (Developing and conducting appropriate experimentation), and 7 (acquire and apply new knowledge).
3. The Data Analysis Phase demands a data-driven solution as determined by assessing the class-wide dataset. Students learn how to generate a scatterplot and apply/assess a trend line, and then calculate the standard deviation and uncertainty of the determined solution. This phase of the activity supports ABET Student Learning Outcomes 1 (identify, formulate, and solve complex engineering problems), 5 (function effectively on a team), and 7 (acquire and apply new knowledge).

The conceptual quiz assessment and anonymous class reviews demonstrates positive feedback from students, indicating increased understanding and a strong appreciation for the real-world application of engineering concepts. A surprising number of students also expressed appreciation for the historical context of the quadrant device.

This paper provided practical advice for implementing the activity. A brief summary of the key conclusions:

- The Mariner's Quadrant Activity aligned well with ABET Student Outcomes 1,4,5,6, and 7.
- There are many options to customize the activity, or to scale up or scale down.
- The historical roots of the Mariner's Quadrant successfully sparks curiosity and draws students into the lesson.
- The analogue nature of the quadrant tool provides a tactile, hands-on experience when solving a real-world challenge in their own, familiar campus environment.
- The experiential learning activity provides a demonstrable improvement (upwards of ~55% increased success rate) in the students' understanding and successful application of active data analysis skills, such as understanding and calculating standard deviation and uncertainty, and applying and assessing the quality of trend lines.
- The activity improves clarity and understanding of more abstract topics, such as the variable sensitivity and verification/validation in preparation for further development in the curriculum.

5.2 Follow-up resources

The assignment prompt is available in Appendix A. Further assignment details, files, and sample solutions are available for use upon request. Please contact the lead author for resources.

6. Acknowledgements

The author would like to express gratitude to the Department of Mechanical Engineering of Auburn University for supporting the development and implementation of the Mariner's Quadrant activity. Additionally, many thanks to the teaching assistants and the ME3D Laboratory student workers whose efforts have made this endeavor possible.

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8. Appendix A

Experimental Data Collection & Analysis

ENGR 1110 Adventure Activity

Learning Objectives: After this lab, you will be able to:

Explain in your own words: The challenges involved in and the importance of collecting accurate experimental data.

Identify: The process for analyzing a large batch of field data to obtain a single result with accompanying standard deviation.

Task 1: Use a Mariner's Quadrant to measure the height of Samford Hall's clocktower!

Task 2: Process the collected experimental data using Microsoft Excel.

What is a "Quadrant" tool?

The Quadrant is a historical engineering tool revered in many disciplines!

The first quadrant tool was invented by the Greeks circa 240 B.C., and it has been remade in several forms for many different purposes throughout history.

The Mariner's Quadrant, for example, is possibly the simplest version, which was used by sailors to determine their latitude by measuring the angle between the horizon and the North Star. Other, more complex versions were used by astronomers for celestial studies and by artillery officers to precisely aim weaponry.

Many quadrants were even engraved with a "Shadow Square", which is a graphical method used to determine the tangent or cotangent of an angle of interest. Imagine how useful this could be to individuals at sea or on a battlefield during an era without calculators or smartphones!

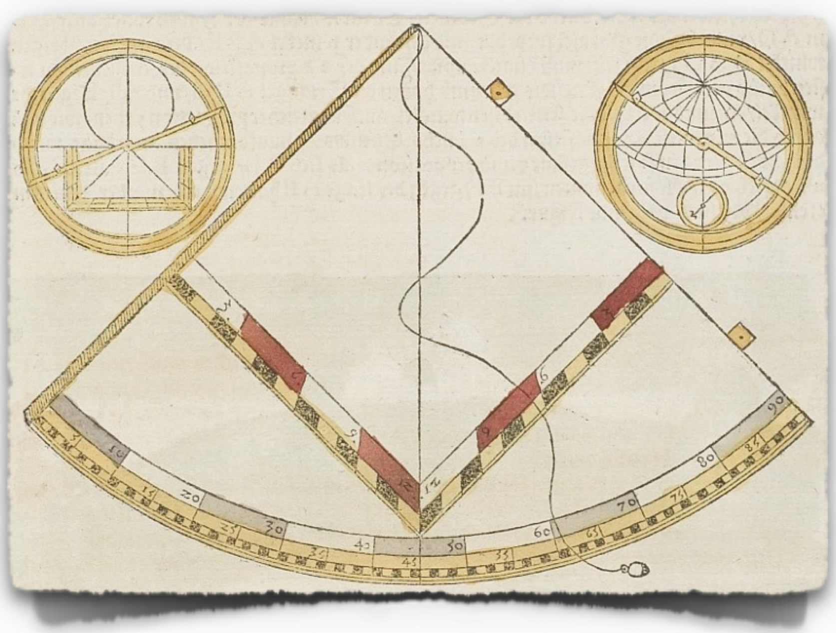
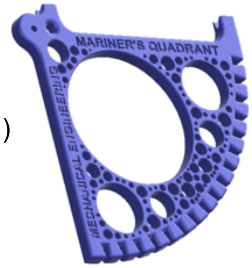
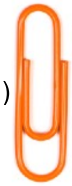


Image Artist: Petrejus, Johann (Drucker) Date: 1547 Image generously released into the Public Domain by the Deutsche Fotothek of the Saxon State Library / State and University Library Dresden (SLUB).

Task 1: Assemble the Quadrant and Collect Experimental Data!

(a) To assemble the quadrant, the required materials are as follows:

Base Quadrant (x1) 

Paperclip (x1) 

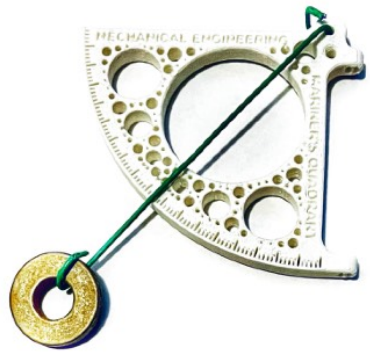
Washer (x1) 

(b) Insert the bead chain into the larger corner hole, as demonstrated below.

(c) Unfold and form the paperclip into the shape indicated below. Insert the paperclip into the Quadrant's corner hole. Bend the end of the paperclip to secure it to the quadrant. Ensure the paperclip freely swings without resistance.

(d) Bend the free end of the paperclip like a hook, such that a washer can be secured and suspended like a pendulum.

(e) The finished assembly should look as so:



(f) Visit Samford Hall and stand directly in front of the clocktower.

(g) Each team member should take 3 total measurement sets (angle and distance) using the Prototype Quadrant, as indicated in Schematic 1 on the next page.

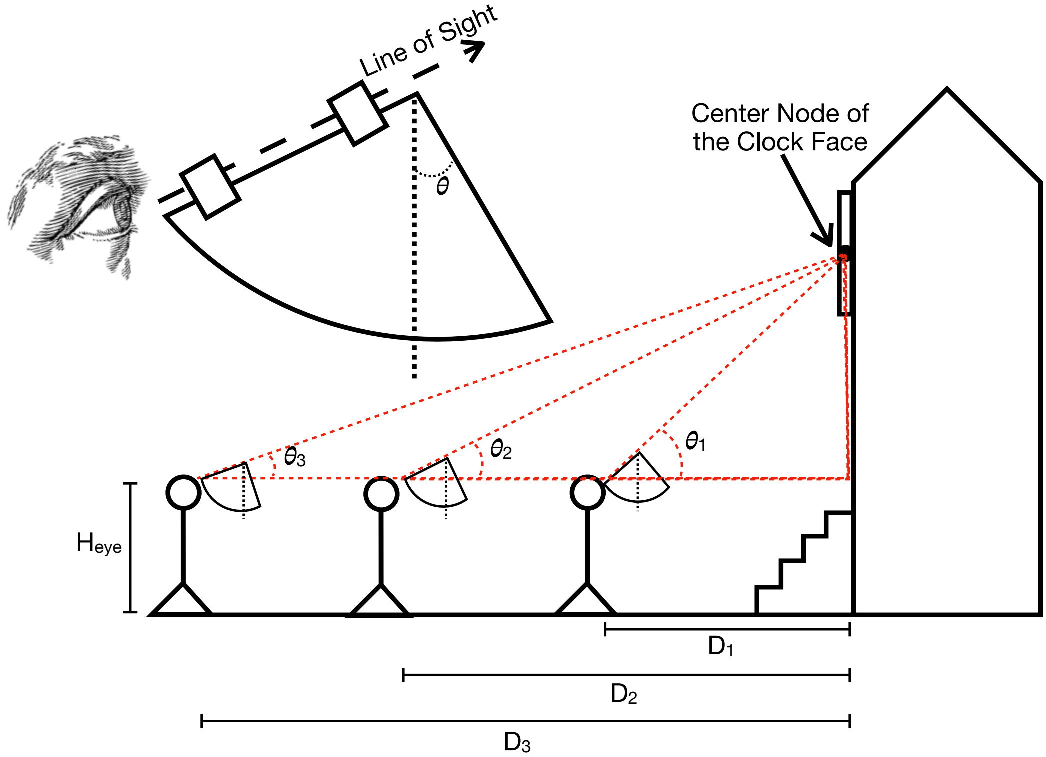
- An easy way to measure the distance from your position to the base of the tower is to count and measure heel-toe footsteps.
- The angle can be measured with the quadrant by looking through the sights at the center node of the clock face and reading the angle at which the paperclip lays against the quadrant marks.

Record the collected data in Table 2.

(h) Analyze the data by calculating the height of the clocktower (i.e. distance from the ground to the center node of the clock face) via Equation 2. Record the resulting heights in Table 2.

(Eq. 2) $$h_{total} = h_{eyes} + [D * tan(\theta)]$$

where h_{total} is the height of the clock face center node, h_{eyes} is the height from the ground to the viewers eyes, D is the distance from the base of the clocktower to the viewer, and θ is the angle measured with the prototype quadrant tool.



Schematic 1: Quadrant Use and Field Setup Schematics.

Table 2: Quadrant Field Data

Team Member	H_{eye} [ft]	D [ft]	θ_1 [°]	H_{total} [ft]
		41.1	68.0	106.9
Bilbo Baggins	5.17	101.1	45.0	106.3
		196.1	27.5	107.3

Task 2: Analyze the Experimental Data

(a) Enter your field data into the provided excel form sheet (available via the online assignment) and upload it to Canvas. The data for the entire section will be made available to you—*it is this data you will use to complete the following tasks*:

(b) **Generate a scatterplot of the Clocktower Height vs Distance.** This means that Total Distance will be plotted on the x-axis, and the Clocktower Height will be plotted on the y-axis.

(c) **Apply a linear trend line** to the scatterplot of the cumulative class data and **report the trend line equation and r^2 value**. The r^2 value describes how well the equation fits the data. An r^2 value of 1 is an ideal 1:1 fit! A good fit is typically in the range of 0.9-1.

(d) **Calculate the standard deviation** of the cumulative class data using Equation 3.

(Eq. 3) $$\sigma = \sqrt{\frac{\sum (h_{total} - h_{mean})^2}{N}}$$

where h_{total} is the height of the clock face center node, h_{mean} is the mean of all the h_{total} results, and N is the total number of data entries.

(e) **Calculate the average clocktower height of the cumulative class data.** This clock tower height is the consensus!

(f) Answer the following Questions:

1. At which distance(s) did the quadrant become a less effective in measuring the height of the clocktower?
2. What causes the phenomenon in Question 1?

Summary of Assignment Deliverables

	Deliverable	Points	Deadline
1	Excel File of Team Data (Distance, Angle, Clocktower Height)	**25**	**24 Hours after lab.**
2	Clocktower Height vs. Total Distance Scatterplot w/Trendline	25	Midnight prior to the next lab session.
3	Standard Deviation of Clocktower Height Calculations	20	
4	Average Clocktower Height	20	
5	Answers to Questions 1 & 2	10	
	Sum:	**100**	

9. Appendix B

Name: ______________________ *Email:* _______________________ *ENGR 1110*

Instructions: *This activity is assessed on participation.* Please answer each question to the best of your ability without using outside resources (i.e. internet, textbooks, peers, etc).

1. *Scenario*: The height of a redwood tree is measured independently by each park ranger assigned to the region: 250 feet, 275 feet, 265 feet, 270 feet, 268 feet, and 273 feet. Which equation should be used to calculate the standard deviation?

   a) $\sigma = \sqrt{\frac{1}{N}\sum(x_i - \mu)^2}$

   b) $s = \sqrt{\frac{1}{n-1}\sum(x_i - \overline{x})^2}$

2. Which of the following statements best describes variable sensitivity?

   a) A measure of how much a system's output changes, linearly or non-linearly, in response to input variables.
   b) A measure of how much a system's output randomly changes while accounting for and excluding controlled input variables.
   c) A measure of how much a system's output linearly changes in response to controlled input variables.
   d) A measure of sensitivity that remains constant over time, regardless of operating conditions.

3. Scenario: A car's steering system is designed to be more sensitive to small steering movements at low speeds but less sensitive at high speeds. This is an example of:

   a) Variable sensitivity with a linear relationship to operating conditions.
   b) Variable sensitivity based on operating conditions.
   c) Threshold insensitivity.
   d) Feedback control insensitivity.

4. Of the following r^2 *values*, which represents the best fit?

   a) 0.999
   b) 0.98
   c) 0.9
   d) 0.8

Name: ________________________ *Email:* _________________________ *ENGR 1110*

5. Is the following scenario an example of *Verification* or *Validation?*
   Scenario: Two students in the same college class compare their answers to a homework problem.

   a) Validation
   b) Verification

6. Examine the image of a ruler below. What is the uncertainty of the ruler?

   Report the uncertainty here (don't forget the units): ____________________________