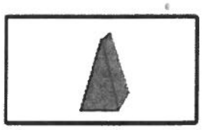
SIMPLE MACHINES DESIGN CHALLENGE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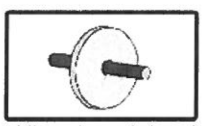
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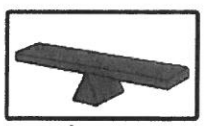
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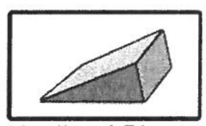
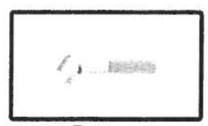
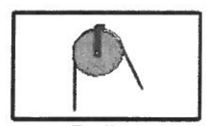

Inclined Plane


Screw


Pulley

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OUR SCHEDULE!

SIMPLE MACHINES INTEGRATED UNIT

PART 1 – Simple Machines

Day 1 - Introduction & Exploration, Goal-setting, SMATHO game
Day 2 - Investigation Stations & Discussion
    Give Take Home Test Questions (3 questions)
Day 3 - Lever Bell Ringer, Lever Experience & Lever Discussion
Day 4- Lever Notes:
    Concepts, Lab Analysis
    Formulas, practice problems
Day 5 - Lever Check Question, Inclined Plane Discussion, Inclined Plane Bell Ringer & Experience
Day 6 - Inclined Plane Notes:
    Concepts, Lab Analysis
    Formulas, practice problems
Day 7 - Inclined Plane Check Question, Pulley Bell Ringer, Lab Prep & Practice, Video
Day 8 - Pulley Experience
Day 9 - Pulley Notes:
    Concepts, Formulas, Practice Problems
    Pulley Check Question
    Quest Review
Day 10 – QUEST & Take Home 3 questions due
Day 11 - Parabola Scavenger Hunt
    Design Challenge Task List Brainstorm
Day 12 - Projectile Motion Discussion & Dart Lab - Data Collection, Graphing
Day 13 - Projectile Motion:
    Lab Analysis, Reflection, Extension
    Video Physics 1 - Recording, Track & Plot Points
Day 14 - Projectile Motion:
    Finish Video Physics - Get data from Logger Pro & put into Nspire

PART 2 – DESIGN CHALLENGE

Day 15 - Design Challenge 1: Design, Budget, Supply List
Day 16 - Design Challenge 2: Materials, Research, Teach & Explain
Day 17 - Design Challenge 3: Build & Test
Day 18 - Design Challenge 4 & 5: Group Feedback, Clean-Up, Self-Reflection, Conference Prep
Day 19 - Conference Prep & Conferences, Design Challenge 6
    DESIGN PHASE: Budget/Supply List, Plans/Drawings, Math Concepts, Rationale/Uses, Photo Timeline (1 page)
    CONSTRUCTION PHASE: Photo Timeline (1 page), Video, Reflections

Simple Machines

Part 1

SIMPLE MACHINE UNIT

Pre-Assessment & Goal Setting

What do you already know about Simple Machines?

Step 1. Complete a Concept Map surrounding the central term "simple machines"

- Select words or phrases that come to mind when you hear the term "simple machine"
- Write these words around the central term
- Connect to the central term using a line
- Write a short description of how these terms connect, on the connecting line
- (Shoot for 5-7 terms)

SIMPLE MACHINES

Step 2. Goals

- Think of this new project and your new project group. What will you accomplish together?

- Write 3 personal goals for this project.

- Write 3 group goals.

Simple Machines BINGO

1. The wheelbarrow is an example of this class of lever. (2nd)
2. A see-saw is an example of this class of lever. (1st)
3. Tweezers are an example of two of this class of lever put together. (3rd)
4. BLANK fill in: this is an example of a place in Cleveland where a PULLEY is used.
5. BLANK fill in: this is an example of a place in Cleveland where a WEDGE is used.
6. This lever is the effort and resistance forces on OPPOSITE sides of the fulcrum. (1st)
7. BLANK fill in: An inclined plane reaches a height of 2 meters at a distance of 4 meters long the floor. What is the slope of this inclined plane? (0.5 m)
8. BLANK fill in: This is a specific early use of a wheel & axle
9. This pulley stays attached to a height above the load to be lifted. (fixed)
10. This pulley is attached to the load and lifts with it. (movable)
11. This version of an inclined plane wraps around a surface (screw)
12. This simple machine focuses a broad amount of effort to one specific point (wedge)
13. When hammering a nail, you are actually using a wedge! When using the opposite side of the hammer to remove that same screw, you are actually using a ________________ (lever)
14. A doorstop is an example of this kind of simple machine (wedge)
15. This part of the car is a long, cylindrical shape that when rotated, can spin the wheels. (axle)
16. A lid of a jar features this kind of simple machine (screw)
17. A fishing pole is an example of this kind of lever (3rd class lever)
18. A wheelchair ramp is an example of this kind of simple machine (inclined plane)
19. A crane is an example of this kind of simple machine (pulley)
20. On a wheelbarrow, the wheel part actually serves as the ______________. (fulcrum)

Simple Machines SMATH Bingo

S	M	A	T	H
screw	movable pulley	inclined plane	2nd class lever	wedge
1st class lever	fulcrum	2nd class lever	fulcrum	screw
axle	inclined plane	Stamp if you L-O-V-E SMATH!	3rd class lever	wedge
1st class lever	lever	3rd class lever	movable pulley	fixed pulley
*	*	*	*	pulley

SIMPLE MACHINES INVESTIGATIONS

THE LEVER

Purpose: Investigate the structure, function, and mechanical advantage of the lever.

Components: Load, effort force (spring scale), lever arm, fulcrum

Task: Using the lever components available to you, build a lever system to lift a 200g load off the table.

Essential Questions & Considerations:

- How does the system change if you organize a 1st, 2nd, or 3rd class lever?
- Consider the relationship between the distance from the LOAD to the fulcrum and the EFFORT to the fulcrum.
- What patterns emerge as you gradually alter your lever design?
- Which component travels a further vertical distance – the load or the effort, and when?
- Do any designs not work, and why?

Timed Talk[1]:
Upon completion of several lever systems, have each person in the group complete a 60-second timed talk about lever systems. (What did you learn? How does it work? What are all the components? When could this system be useful? Etc)

---

[1] A *Timed Talk* is when one person has the floor for a set length of time. During this time, they should be the only one talking, and strive to speak for the entire time. The goal is to verbalize understandings – and remaining questions – without interruption. Someone else in the group may be designated as time keeper to give the speaker a fair length of time.

Investigation Notes

As you visit each station and investigate as a group, take notes based on the essential questions.

Question	My Notes (or diagrams)
How does the system change if you organize a 1st, 2nd, or 3rd class lever?	
Consider the relationship between the distance from the LOAD to the fulcrum and the EFFORT to the fulcrum.	
What patterns emerge as you gradually alter your lever design?	
Which component travels a further vertical distance – the load or the effort, and when?	
Do any designs not work, and why?	

SIMPLE MACHINES INVESTIGATIONS

INCLINED PLANE

Purpose: Investigate the structure, function, and mechanical advantage of the inclined plane.

Components: Load with transport unit, effort force (spring scale), ramp, blocks

Task: Build different slopes of the inclined plane with varying numbers of blocks. Investigate the change in effort force required to move the 1-kg load with each different inclined plane.

Essential Questions & Considerations:

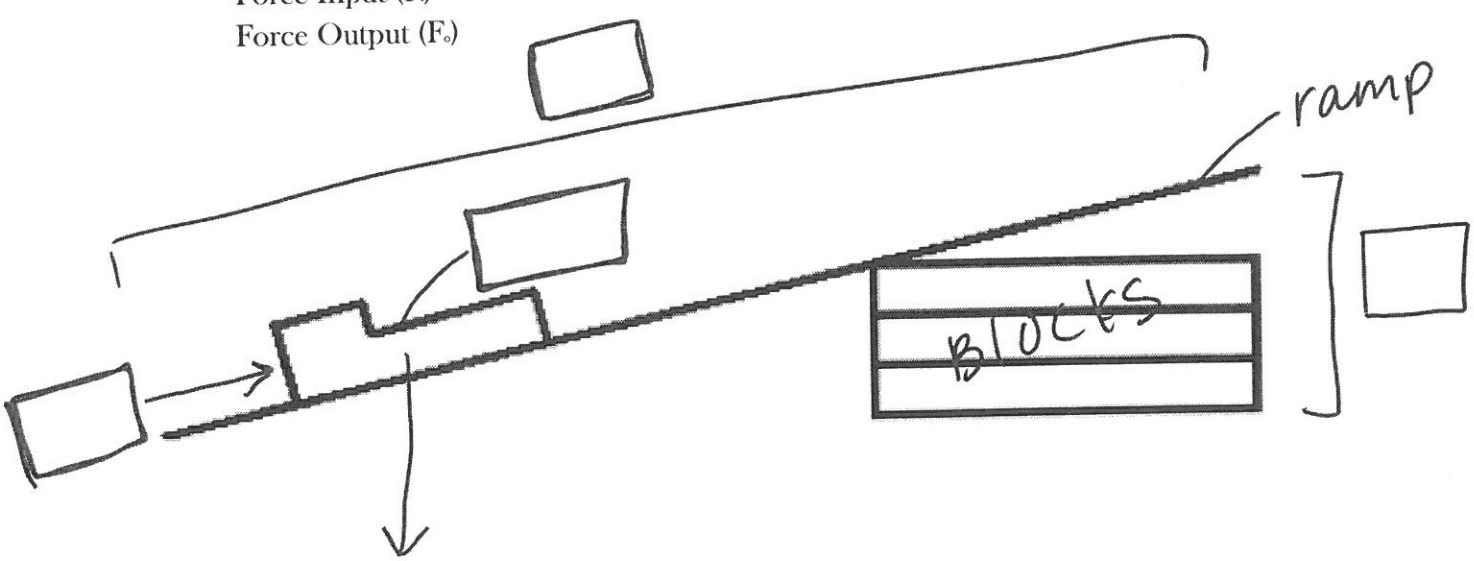
- How does the slope of your plane change when using 1, 2, 3, 4, or 5 blocks as a support?
- How does an inclined plane reduce the effort force required? Compare the effort force needed to lift a load straight up versus utilizing the inclined plane at various slope angles.
- What patterns emerge as you increase your slope?
- How could you improve the efficiency of your machine – meaning, getting the most out of your effort put in?

Diagram:

On the below diagram, decide as a group how to label each of the 5 variables. We will review these on our specific inclined planes investigation day.

Label the:

Load
Distance Input (D_i)
Distance Output (D_o)
Force Input (F_i)
Force Output (F_o)



Investigation Notes

As you visit each station and investigate as a group, take notes based on the essential questions.

Question	My Notes (or diagrams)
How does the slope of your plane change when using 1, 2, 3, 4, or 5 blocks as a support?	
How does an inclined plane reduce the effort force required? Compare the effort force needed to lift a load straight up versus utilizing the inclined plane at various slope angles.	
What patterns emerge as you increase your slope?	
How could you improve the efficiency of your machine – meaning, getting the most out of your effort put in?	

SIMPLE MACHINES INVESTIGATIONS

PULLEY

Purpose: Investigate the structure, function, and mechanical advantage of the pulley.

Components: 200g load, effort force (measured by spring scale), string, pulley units, ring stand

Task: Assemble a simple fixed and a simple movable pulley using the materials available to you. Investigate the relationship between the pulley organization and the effort required to lift a load. Also, notice the direction of the forces and movement for both fixed and moveable pulley systems

Essential Questions & Considerations:

- In what ways is a pulley like the fulcrum of a lever? Which class of lever is a pulley?
- Does a fixed (single) pulley provide any mechanical advantage? Does it reduce the effort required?
- Does a moveable pulley provide any mechanical advantage? Does it reduce the effort required, and if so, by how much?
- What factors of the string itself can reduce the efficiency of the machine? Describe an ideal type of string to use in your pulley system.
- What is the direction of movement on each side of the pulley? (You will diagram this in the notes)

Skit:

Improvise a short skit between your group. This should be a conversation between the characters. "Improvise" means you do not write down any lines; each person just knows their character and doesn't break from it! Use the equipment provided to you as props in your skit.
When you are ready, call your teachers over to show them your dialogue.

Here are the characters:
Character 1: A person considering installing an elevator in their small apartment building
Character 2: A construction manager who needs to know all the parts and pieces required to build the elevator
Character 3: An expert on fixed pulleys who wants to explain the benefits of using a single fixed pulley for the elevator
Character 4: An expert on movable pulleys who wants to explain the benefits of using a single movable pulley for the elevator
(If you only have 3 people in your group, character 3 & 4 are combined)

Investigation Notes

As you visit each station and investigate as a group, take notes based on the essential questions.

Question	My Notes (or diagrams)
In what ways is a pulley like the fulcrum of a lever? Which class of lever is a pulley?	
Does a fixed (single) pulley provide any mechanical advantage? Does it reduce the effort required?	
Does a moveable pulley provide any mechanical advantage? Does it reduce the effort required, and if so, by how much?	
What factors of the string itself can reduce the efficiency of the machine? Describe an ideal type of string to use in your pulley system.	
What is the direction of movement on each side of the pulley? Diagram each pulley and note direction of movement.	

SIMPLE MACHINES INVESTIGATIONS

PROJECTILE MOTION

Purpose: Investigate the motion produced when simple machines provide velocity to an object.

Components: Measuring tape, squishball, catapult, elastic band, bucket

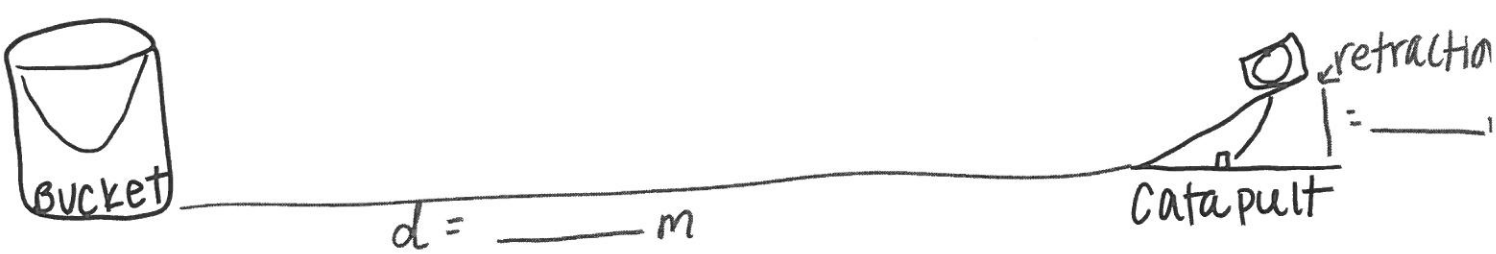
Task: Launch a targeted squishball to land in a bucket. Determine the distance from the bucket and the retraction of your catapult necessary to hit the target.

Essential Questions & Considerations:

- How does the shape and mass of your squishball affect the location of your catapult, relative to the bucket? Experiment with different sizes and masses of projectiles.
- What is the relationship between the location of your catapult and the retraction of your catapult? When you are closer to the bucket, is your catapult pulled back more or less? Why?
- Consider the velocity of the squishball in both the vertical (up and down - perpendicular to the ground) direction and horizontal (side-to-side - parallel to the ground) direction. How are the horizontal and vertical velocities of the squishball working together to bring the squishball to the bucket?
- Once you've determined a good location for your catapult, what's your success rate? Are you able to get 3 in the bucket a row? Why or why not?
- What is the shape of the path of your squishball as it flies through the air?

Design Plans:

Use the diagram below to document your catapult set up. Label your measurements clearly, so someone else could re-create your design. You should label the distance from the catapult to the bucket and the retraction distance (how close is the squishball to the base of the catapult before you launch?) Using a different color pen, sketch in the path of your squishball as it travels from the catapult to the bucket.



Investigation Notes

As you visit each station and investigate as a group, take notes based on the essential questions.

Question	My Notes (or diagrams)
How does the shape and mass of your squishball affect the location of your catapult, relative to the bucket? Experiment with different sizes and masses of squishballs.	
What is the relationship between the location of your catapult and the retraction of your catapult? When you are closer to the bucket, is your catapult pulled back more or less? Why?	
Consider the velocity of the squishball in both the vertical (up and down – perpendicular to the ground) direction and horizontal (side-to-side – parallel to the ground) direction. How are the horizontal and vertical velocities of the squishball working together to bring the squishball to the bucket?	
Once you've determined a good location for your catapult, what's your success rate? Are you able to get 3 in the bucket a row? Why or why not?	
What is the shape of the path of your squishball as it flies through the air?	

SIMPLE MACHINES INVESTIGATIONS

SIMPLE MACHINES INTERVIEWS

Purpose: Watch and learn as other students dialogue with experts about simple machines.

Components: Simple Machines Video:
http://idahoptv.org/sciencetrek/topics/simple_machines/index.cfm?id=2

Task: As a group, watch the video. Pause the tape after each student's question is answered. Chat as a group about what was just said, and take notes about these essential questions.

Essential Questions & Considerations:

- What is the benefit of using simple machines?
- Why isn't something like "homework" considered work in the physical sense? What formula can scientists use to measure work?
- What is the history of simple machines? Who were the specific people and cultures involved in the first use and labelling of simple machines?
- What is the difference between "Newtons" and "Joules"?

Calculate:
If a 2 Newton load will be lifted 2 meters, how much Work is done? See if you can use the formula described during the video to calculate. Remember, the units of Work are the same as Energy – which means the units of Work are also *Joules.*

Investigation Notes

As you visit each station and investigate as a group, take notes based on the essential questions.

Question	My Notes (or diagrams)
What is the benefit of using simple machines?	
Why isn't something like "homework" considered work in the physical sense? What formula can scientists use to measure work?	
What is the history of simple machines? Who were the specific people and cultures involved in the first use and labelling of simple machines?	
What is the difference between "Newtons" and "Joules"?	

PROJECTILE MOTION
VIDEO PHYSICS – Part 1

YOUR TASK:
With your group, you are going to record the path of a projectile using the Video Physics App on the I-Pads.

Your group needs to decide what method you would like to launch:

~Using a catapult to toss a ball into a bucket
~Tossing a ball into a bucket
~Tossing a ball between 2 people

STEPS TO FOLLOW:
DRAW

1. Draw a diagram of what you think the path of the ball will look like:

LAUNCH

1. Choose your Roles (record on the table below)
    a. Camera Operator
    b. Catapult Captain
    c. Bucket Boss/Receiver
    d. Measure Master
2. Set-up your Trajectory
3. Practice your Launch once or twice
    Make sure that the entire path will be in the video screen
4. Measure the Bucket or another Reference Image that will be in the video (record on the table below)

VIDEO PHYSICS

1. Open the Video Physics App
2. Record your Launch using the Video Physics App
   - Click on the + in the upper left corner
   - Choose take video
   - Record your launch
     - *Do not move or zoom the camera while recording
3. Click on Use Video (bottom right)
4. Click on Origin & Scale
   - Move the axis
   - Set the Scale 1px = Height of Bucket or Image
5. Click on Points
   - Line up the "target"
   - Click on Track
   - Plot points along the path of the ball
     - *More points is better to have a more accurate graph*
6. Click on the Graph (Upper Right) to view the graph of your projectile
7. Click on the Email (Upper Right, next to Graph), email your DATA FILE to your group members
   - *Do not do anything with your email tonight – we will use it tomorrow in class!

Method of Launch	
Camera Operator	
Catapult Captain	
Bucket Boss/Receiver	
Measure Master	
Height of Bucket or Reference Image	

PROJECTILE MOTION
VIDEO PHYSICS – Part 2

YOUR TASK:
With your group, you are going to create a graph of the path that your ball followed during the launch yesterday.

Your group will need to access the DATA FILE that was emailed from the I-Pad Video Physics program yesterday.

**Each person in your group needs to create their own graph.

STEPS TO FOLLOW:
1. Open EMAIL with your groups file
   Double click on .cmbl file to open data file

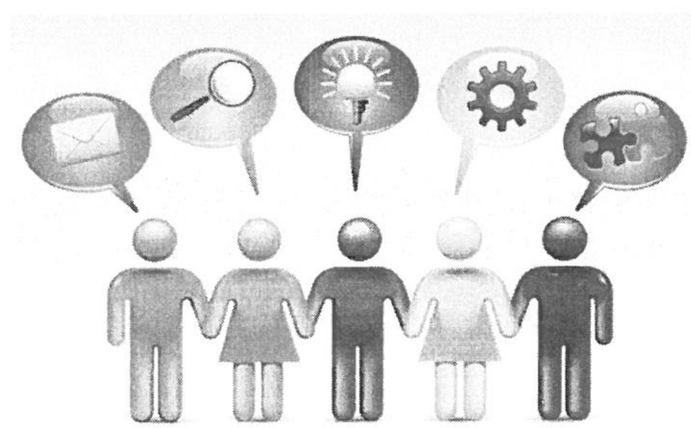
2. In LOGGER PRO, you should see the graphs of your data
   Click INSERT – TABLE
   You will need to COPY the TIME & Y (meters/feet) columns into NSpire

3. Open NSPIRE
   Choose LISTS & SPREADSHEETS
   PASTE the table that was created in Logger Pro
   Label the Columns TIME & HEIGHT (in the top row, next to the letters)

4. To GRAPH:
   INSERT Graph
   Click on the TOOLBOX icon
   Choose GRAPH/ENTRY
   Choose SCATTERPLOT
      At the top, put in X Time & Y Height (click enter)
   ADJUST your window to create a larger view of the graph

5. To get the EQUATION/FUNCTION:
   Click on the TOOLBOX icon
   Click on GRAPH/ENTRY
   Choose FUNCTION
   Type in $-X^2$ to start with
   Move the graph around, stretch or shrink it to get a PARABOLA of best fit
   With the equation showing, SNIP the graph below:

READINGS
&
DISCUSSIONS



DISCUSSION MODEL

Introducing and Using the Discussion (AKA, Harkness) Table

Brian Mullgardt
Fall 2008

International affairs expert Fareed Zakaria has recently suggested that America's edge in education comes from its habit of making students *think*rather than just memorize and regurgitate (191-195). Discussion based teaching (also called the "Harkness method," after the oval discussion tables designed to facilitate conversation) challenges students to sit at the center of education, making meaning of new information together, talking, listening, and ultimately *thinking*. While some schools have relied on the method for many years, others, like mine, have not. In such cases, introducing this style of learning, in which no student can hide, can be difficult if students aren't used to it, and making sure it's productive also presents challenges. However, once included in a curriculum it allows students to more deeply understand material and think for themselves.

When I began my job at an independent school six years ago, my pedagogical style was very open, but I held to one vow: no more teaching via discussion. Having previously taught in university History departments, I had come to view discussion based teaching as slow death, doled out in fifty minute blocks characterized by silence, blank stares, and lidded eyes. However, knowing that to perform well in college my high school students needed to be experienced in discussion (see the Center for History and New Media's www.chmn.syllabi for a large repository of university syllabi that include discussion in the averaging of grades), I decided to integrate it into my syllabus.

The first step to consider if you wish to effectively introduce discussion is enrolling in the Phillips Exeter Academy Humanities Institute (www.exeter.edu/summer_programs/9398.aspx). Held every summer on Exeter's campus, teachers gather to share ideas about and model discussion based teaching. Most helpful to me was the red binder of materials the Exeter teachers had collected, including articles about the Harkness method, and tools for assessing discussion. In particular, the top-down diagram of the discussion table used to track who spoke to whom encouraged me to bring more discussion to class because now I could more accurately assess it.

I teach mixed ability 11th graders in U.S. History, some of whom would resist being forced to sit around a table facing each other and sharing ideas for a grade. They were used to participating in class, but not engaging in a totally student-centered, assessed activity. If I were alone in bringing this new and challenging style I'd look crazy, villainous, or both. On returning to my school in the fall, I shared my experiences with colleagues, and two agreed to include more discussion in their English classes. Enlisting others to include discussion is the next important step to introducing it: with two other teachers of the same grade level using discussion to teach and assess, it gained credibility and offered students practice in other classrooms. When a couple of students decided they had "the right to remain silent," saying that this was cruel and unusual punishment, they also saw that other teachers valued it. It is important as well to get your superiors on board; I spoke to mine to explain why and how I was integrating it, so he could field any phone calls from concerned parents.

The next step was to prepare students for their first round of totally student-centered learning. If they arrived to class cold, unaware of what was expected of them, silence would surely follow. So, I designed each discussion day around one essential question, posed on my syllabus. I then took a day of class to allow students, in pairs, to brainstorm about the first question ("Why would colonists want to wage war against Britain?"), jot down ideas, and think of other questions to ask the class. I also gave them a handout titled "Guidelines for Discussion," taken right from the Exeter red book (thanks to Ralph Sneeden) with important tips such as "collaborate, don't compete" and "do not address everything to the instructor." This provided some friendly tips, and some ground rules.

On our first day of discussion, students sat around a large table facing each other, and I sat several feet away from it, allowing them to figure out where things would go while I charted who spoke to whom. One of the first tips offered at Exeter was "let go," and it's the next important step in discussion based teaching. I've learned that my previous style of "leading" discussion was more Initiation-Response-Evaluation, in which a teacher offers Socratic questions in a call-and-response format, telling the student if he/she is correct, rather than a true discussion, where the role of the instructor is minimized to make room for student exploration (Levstik and Barton 21). Now, I "let go," and interjected only to move them from topic to topic, correct erroneous information, or to ask a student to clarify a point. The class was initially silent, as the scenario was, to them, awkward. But the silence was uncomfortable for them, especially since their performances were to be graded, and this forced them to think on their feet and address that day's materials.

The initial results were better than I expected. In a class of 17 students, approximately 15 spoke, some more than others. At the end of class, each student filled out and turned in a confidential peer review of one other student, assigned by me at the start of the hour. I then showed them my diagram of the table, noting that, on that day, students were more comfortable speaking across the table to each other than turning to speak down it. The diagram allowed them to more fully understand the number of individual contributions (throughout the rest of the term I hung each subsequent diagram on the wall for comparison). We ended with a five-minute discussion of the discussion itself, assessing strengths and weaknesses to think about for next time. As the year progressed, students who previously loathed history told me they came to like it, because now it concerned ideas, not "just names and dates." One group of twenty asked that they be split into two sections of ten so that each student would have more opportunities to speak, and I supported their request by holding class over lunch.

After that first year of intermittent discussion in all sections, I moved my Advanced Placement U.S. History class to an all-discussion format, jettisoning lecture entirely. As the year progressed, I witnessed discussions not only of past events, but watched students make connections throughout history, and relate the past to their lives. They also began to discuss the textbook itself. Knowing they would be evaluated on the quality of their participation, they read the text nightly (I suspected they did not when I lectured). By mid-year, they were talking about the author's perspective and voice, which led to discussions about how American history is viewed and written in a post Watergate and Vietnam world. This showed me the benefits of discussion outside of merely preparing students for college. The practice hones their interpersonal skills; they have to find collegial, mature ways to disagree. They have to listen to others, connect points, and police their own conversations. Shy students, while uninspired or terrified by group talks, can build their confidence. Above all, students have to *think*.

Discussion based teaching has taken root at my school, but problems persist. In my regular U.S. History courses I do not offer discussion every day, saving it for Fridays so I can differentiate my instruction during the week. This leads to some students, knowing a grade is attached to discussion, to take it *too* seriously. This can cause anxiety, competition, or chatter for the sake of chatter in hopes of a high grade. I've moved from grading each weekly discussion individually, to assigning a cumulative grade at the end of each month to relieve pressure and encourage more natural discourse. Some students are still shy, even when their classmates are warm and helpful to them ("Would you like to add something, Tommy? It's okay."). For the chronically shy, I tend to go easier on them the first term, but I tell them that I will not continue to do so after that, instead working one-on-one with them in my office prior to discussion to reassure them. And I occasionally face a large section (16 really is maximum for this type of instruction), that requires me to police things more closely to make sure all can be heard, if they wish.

No longer do I eschew discussion, but seek new ways to make it more engaging, whether it be adding a few minutes of documentary or movie footage to get the class thinking, challenging them to "Make me interested" in a subject (then giving them time to huddle up and strategize before we begin) or handing out new primary sources on the spot to read aloud and discuss. Should this teaching style appeal to you, consider the following:

1. Don't introduce it alone, if possible. Try to get colleagues to offer this challenging approach with you. It legitimizes the technique, and gives students practice in other classrooms. Additionally, talk with administration.
2. Post essential questions ahead of time, and work to get students thinking about discussion before it happens.
3. Silence is your friend. Let students reflect and think before they talk. Ultimately, "let go" so *they* can make sense of information.
4. Assess discussion. Students need feedback as to when they're making thoughtful comments, and when not. Track who speaks to whom, and have peers offer input. It also motivates.
5. Do it frequently, or forget it. Including a discussion day every three weeks won't do; students will become rusty, or will place so much emphasis on doing well that one day that it impedes the natural flow.

I still suffer from the occasional flashback of a baseball-hat clad undergraduate, half-asleep at 8am on a Friday morning during discussion. But more often I experience the excitement of watching students talk, agree, disagree, stumble, and recover while making sense of the past. Discussion based teaching has become a central component of my teaching kit-bag, not just because it is good preparation for college, but because it hones thinking skills.

References:

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Simple Machines Discussions Guiding Questions

These accompany selected reading articles contained in this packet.

LEVER

- Go around the circle and answer "yes" or "no": Could Archimedes have lifted the earth?
- Draw a map of the lever required for Archimedes to lift the earth, labelling D_i, D_o, and any measurements.
- Who was Archimedes? Where did he live? (use tablets to look up)
- Why did Archimedes make such a statement? Was he trying to impress (hyperbole) or did he really believe he could do it?
- What other inventions is Archimedes known for? (use tablets to look up)

INCLINDED PLANE

- As a group, create a blueprint for an external ramp to lift the capstone. Include all dimensions. The slope grade should be 8% or less.
- How far away from the center of the pyramid does the ramp originate? (requires knowledge of Pythagorean theorem)
- Using Google Earth, locate a radius surrounding the great pyramids of Giza to match the distance from the question above. What is the environment like in these areas? Could you notice if there were ancient stone quarries? Would the environment have been able to host abundant wood supplies to build the ramp supports?
- Discuss the internal vs. external ramp theories.
- How might pulleys have been used in tandem with a ramp?

PULLEY

- Use the context of the bike gear articles to discuss your experience shifting gears on a bicycle.
- Generate a list of other every day encounters made easier by a pulley system (i.e. classroom blinds, garage door, etc)
- Research the amount of energy expended when pedaling a bike. How is this reduced with the gear system?
- Generate a list of places where you would like to incorporate a pulley to make a job easier.
- Have each student describe the largest pulley system they have ever seen.

PROJECTILE MOTION & TRAJECTORIES

*Interactive discussion, where students are given the following scenarios and tools and asked to discuss and observe patterns:

- Students present questions from the article, discuss new vocabulary
- Define the difference between horizontal and vertical motion
- Watch a video of free fall in a vacuum
- Explore pushing objects off a desk and note fall patterns in both directions
- Contemplate whether the object has movement in both horizontal AND vertical directions at the vertex
- Compare lofting and bouncing paths of objects

Could Archimedes have lifted the earth?

Archimedes, the great mathematician, made a claim to King Hiero of Syracuse that he could move the earth if given a place to stand. But was this really possible? Imagining that he had another planet to stand on and a lever large enough to do so, could he really have moved the earth? Scientifically speaking, yes and no.

Archimedes was a native of Syracuse, Sicily. It is reported by some that he visited Egypt and there invented a device now known as Archimedes screw. This is a pump, still used in many parts of the world. It is presumed that, when Archimedes was a young man, he studied with the successors of Euclid in Alexandria. Certainly he was completely familiar with the mathematics developed there, but what makes this conjecture much more certain, is that he knew personally the mathematicians working there.

"Give me a place to stand and I will move the earth!"

This is a legend ascribed to the famous Archimedes, genius of antiquity who discovered the laws of the lever. "Archimedes," Plutarch says, "Once wrote to King Hiero of Syracuse, whose kinsman and friend he was, that this force could be used to move any weight. Carried away by the power of argument, he added that, were there another earth, he would go there and lift our own planet from it."

King Hiero, who was absolutely astonished by the statement, asked him to prove it. In the harbor was a ship that had proved impossible to launch even by the combined efforts of all the men of Syracuse. Archimedes, who had been examining the properties of levers and pulleys, built a machine that allowed him the single-handedly move the ship from a distance away.

Archimedes knew that by applying a lever, one could lift the heaviest of weights by applying even the weakest of forces. One had only to apply this force to the levers longer arm and cause the shorter one to act on the load. He therefore thought that by pressing with his hand on the extremely long arm of a lever he would be able to lift a weight, the mass of which would be equivalent to that of the earth (For the sake of conceptual clarity, we shall take the "moving" or lifting of the earth to mean the lifting *on the earth's surface* of a weight whose mass would be equivalent to that of the earth).

But, if this great scholar of antiquity would have known what an enormous mass the earth possesses, he would have most likely "eaten his words". Let us imagine for a moment that Archimedes had at his disposal "another earth" and also the point of support he sought. Further imagine that he was even able to manufacture a lever of the required length. I wonder if you can guess the amount of time he would need to lift a load equivalent in mass

Source: http://www.buzzle.com/editorials/7-30-2004-57259.asp, January 18, 2011 to that of the earth, by at least a centimeter? *Thirty million million years*- and no less!!

Astronomers know the earth's mass. On earth a body possessing such a mass would weigh in round numbers 6,000,000,000,000,000,000,000 tons.

Supposing a man could lift only 60 kg directly, to "lift the earth" he would need a lever with a long arm that would be longer than the shorter arm by 1,000,000,000,000,000,000,000 times!!

You can easily figure it out that to have the end of the short arm rise by one centimeter; the other end must describe through space the huge arc of 1,000,000,000,000,000,000 km .

That is the colossal distance Archimedes would have had to push the lever to lift the earth by just one centimeter. So how much time would he need? Presuming Archimedes could have lifted 60 Kg one meter in one second- the work of almost one horsepower! - to lift the earth by just one centimeter, even then he would need 1,000,000,000,000,000,000,000 seconds or 30 million million years. Though he lived to a ripe old age Archimedes and his lever wouldn't have lifted the earth by so much as even the thinnest of hairs.

No artifices would have helped him to cut the time noticeably- despite all his brilliance. For according to the "golden rule" of mechanics, the mechanical advantage derived will always be accompanied by a loss in displacement, or, in other words, in time. Even if Archimedes had been able to push the lever with a speed of 0.34 km/sec the speed of sound, he would have lifted the earth by one centimeter only after 93,264,094,069,895.84265 years .

If he had pushed the lever with the speed of light, 300,000 km/sec, nature's fastest possible- he would have lifted the earth by one centimeter only after *ten million years* of pushing.

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- Lewis, Albert C. "Archimedes." Encyclopedia of World Biography. New York: McGraw-Hill, Inc., 1973. vol. 1, pp.219-223.
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Source: http://www.buzzle.com/editorials/7-30-2004-57259.asp, January 18, 2011

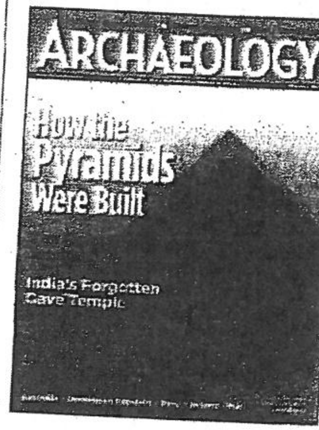
features

Volume 60 Number 3, May/June 2007

How to Build a Pyramid

by Bob Brier

Hidden ramps may solve the mystery of the Great Pyramid's construction.



Of the seven wonders of the ancient world, only the Great Pyramid of Giza remains. An estimated 2 million stone blocks weighing an average of 2.5 tons went into its construction. When completed, the 481-foot-tall pyramid was the world's tallest structure, a record it held for more than 3,800 years, when England's Lincoln Cathedral surpassed it by a mere 44 feet.

We know who built the Great Pyramid: the pharaoh Khufu, who ruled Egypt about 2547-2524 B.C. And we know who supervised its construction: Khufu's brother, Hemienu. The pharaoh's right-hand man, Hemienu was "overseer of all construction projects of the king" and his tomb is one of the largest in a cemetery adjacent to the pyramid.

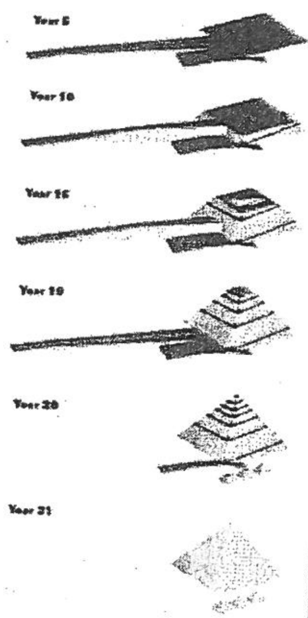
What we don't know is exactly how it was built, a question that has been debated for millennia. The earliest recorded theory was put forward by the Greek historian Herodotus, who visited Egypt around 450 B.C., when the pyramid was already 2,000 years old. He mentions "machines" used to raise the blocks and this is usually taken to mean cranes. Three hundred years later, Diodorus of Sicily wrote, "The construction was effected by mounds" (ramps). Today we have the "space alien" theory--those primitive Egyptians never could have built such a fabulous structure by themselves; extraterrestrials must have helped them.

Modern scholars have favored these two original theories, but deep in their hearts, they know that neither one is correct. A radical new one, however, may provide the solution. If correct, it would demonstrate a level of planning by Egyptian architects and engineers far greater than anything ever imagined before.

The External Ramp and Crane Theories

The first theory is that a ramp was built on one side of the pyramid and as the pyramid grew, the ramp was raised so that throughout the construction, blocks could be moved right up to the top. If the ramp were too steep, the men hauling the blocks would not be able to drag them up. An 8-percent slope is about the maximum possible, and this is the problem with the single ramp theory. With such a gentle incline, the ramp would have to be approximately one mile long to reach the top of the pyramid. But there is neither room for such a long ramp on the Giza Plateau, nor evidence of such a massive construction. Also, a mile-long ramp would have had as great a volume as the pyramid itself, virtually doubling the man-hours needed to build the pyramid. Because the straight ramp theory just doesn't work, several pyramid experts have opted for a modified ramp theory.

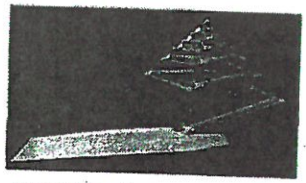
This approach suggests that the ramp corkscrewed up the outside of the pyramid, much the way a mountain road spirals upward. The corkscrew ramp does away with the need for a massive mile-long one and explains why no remains of such a ramp have been found, but there is a flaw with this version of the theory. With a ramp corkscrewing up the outside of the pyramid, the corners couldn't be completed until the final stage of construction. But careful measurements of the angles at the corners would have been needed frequently to assure that the corners would meet to create a point at the top. Dieter Arnold, a renowned pyramid expert at The Metropolitan Museum of Art, comments in his definitive work, Building in Egypt: "During the whole construction period, the pyramid trunk would have been completely buried under the ramps. The surveyors could therefore not have used the four corners, edges, and foot line of the pyramid for their calculations." Thus the modified ramp theory also has a serious problem.



According to the new theory, an external ramp was used to build the lower third of the pyramid and was then cannibalized, its blocks taken through an internal ramp for the higher levels of the structure. (Dassault Systemes) [LARGER IMAGE]

The second theory centers on Herodotus's machines. Until recently Egyptian farmers used a wooden, cranelike device called a shadouf to raise water from the Nile for irrigation. This device can be seen in ancient tomb paintings, so we know it was available to the pyramid builders. The idea is that hundreds of these cranes at various levels on the pyramid were used to lift the blocks. One problem with this theory is that it would involve a tremendous amount of timber and Egypt simply didn't have forests to provide the wood. Importing so much lumber would have been impractical. Large timbers for shipbuilding were imported from Lebanon, but this was a very expensive enterprise.

Perhaps an even more fatal flaw to the crane theory is that there is nowhere to place all these cranes. The pyramid blocks tend to decrease in size higher up the Great Pyramid. I climbed it dozens of times in the 1970s and '80s, when it was permitted, and toward the top, the blocks sometimes provide only 18 inches of standing room, certainly not enough space for cranes large enough to lift heavy blocks of stone. The crane theory can't explain how the blocks of the Great Pyramid were raised. So how was it done?



The complexities of the Great Pyramid's design and construction could not have been deciphered without the aid of 3-D imaging software. (Dassault Systemes) LARGER IMAGE

The Internal Ramp Theory

A radical new idea has recently been presented by Jean-Pierre Houdin, a French architect who has devoted the last seven years of his life to making detailed computer models of the Great Pyramid. Using start-of-the-art 3-D software developed by Dassault Systemes, combined with an initial suggestion of Henri Houdin, his engineer father, the architect has concluded that a ramp was indeed used to raise the blocks to the top, and that the ramp still exists--inside the pyramid!

The theory suggests that for the bottom third of the pyramid, the blocks were hauled up a straight, external ramp. This ramp was far shorter than the one needed to reach the top, and was made of limestone blocks, slightly smaller than those used to build the bottom third of the pyramid. As the bottom of the pyramid was being built via the external ramp, a second ramp was being built, inside the pyramid, on which the blocks for the top two-thirds of the pyramid would be hauled. The internal ramp, according to Houdin, begins at the bottom, is about 6 feet wide, and has a grade of approximately 7 percent. This ramp was put into use after the lower third of the pyramid was completed and the external ramp had served its purpose.

The design of the internal ramp was partially determined by the design of the interior of the pyramid. Hemienu knew all about the problems encountered by Pharaoh Sneferu, his and Khufu's father. Sneferu had considerable difficulty building a suitable pyramid for his burial, and ended up having to construct three at sites south of Giza! The first, at Meidum, may have had structural problems and was never used. His second, at Dashur--known as the Bent Pyramid because the slope of its sides changes midway up--developed cracks in the walls of its burial chamber. Huge cedar logs from Lebanon had to be wedged between the walls to keep the pyramid from collapsing inward, but it too was abandoned. There must have been a mad scramble to complete Sneferu's third and successful pyramid, the distinctively colored Red Pyramid at Dashur, before the aging ruler died.

From the beginning, Hemienu planned three burial chambers to ensure that whenever Khufu died, a burial place would be ready. One was carved out of the bedrock beneath the pyramid at the beginning of its construction. In case the pharaoh had died early, this would have been his tomb. When, after about five years, Khufu was still alive and well, the unfinished underground burial chamber was abandoned and the second burial chamber, commonly called the Queen's Chamber, was begun. Some time around the fifteenth year of construction Khufu was still healthy and this chamber was abandoned unfinished and the last burial chamber, the King's Chamber, was built higher up--in the center of the pyramid. (To this day, Khufu's sarcophagus remains inside the King's Chamber, so early explorers of the pyramid incorrectly assumed that the second chamber had been for his queen.)

Huge granite and limestone blocks were needed for the roof beams and rafters of the Queen's and King's Chambers. Some of these beams weigh more than 60 tons and are far too large to have been brought up through the internal ramp. Thus the external ramp had to remain in use until the large blocks were hauled up. Once that was done, the external ramp was dismantled and its blocks were led up the pyramid via the internal ramp to build the top two-thirds of the pyramid. Perhaps most blocks in this portion of the pyramid are smaller than those at the bottom third because they had to move up the narrow internal ramp.

There were several considerations that went into designing the internal ramp. First, it had to be fashioned very precisely so that it didn't hit the chambers or the internal passageways that connect them. Second, men hauling heavy blocks of stones up a narrow ramp can't easily turn a 90-degree corner; they need a place ahead of the block to stand and pull. The internal ramp had to provide a means of turning its corners so, Houdin suggests, the ramp had openings there where a simple crane could be used to turn the blocks.

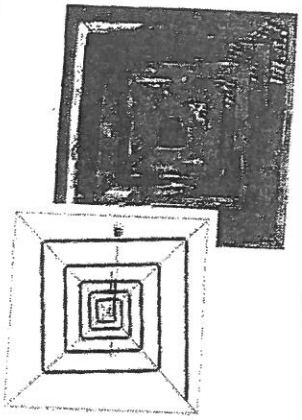
Wooden hoists on notches left in the edge of the pyramid could have been used to turn blocks onto the next part of the internal ramp. (Dassault Systemes) LARGER IMAGE

There are plenty of theories about how the Great Pyramid could have been built that lack evidence. Is the internal ramp theory any different? Is there any evidence to support it? Yes.

A bit of evidence appears to be one of the ramp's corner notches used for turning blocks. It is two-thirds of the way up the northeast corner--precisely at a point where Houdin predicted there would be one. Furthermore, in 1986 a member of a French team that was surveying the pyramid reported seeing a desert fox enter it through a hole next to the notch, suggesting that there is an open area close to it, perhaps the ramp. It seems improbable that the fox climbed more than halfway up the pyramid. More likely there is some undetected crevice toward the bottom where the fox entered the ramp and then made its way up the ramp and exited near the notch. It would be interesting to attach a telemetric device to a fox and send him into the hole to monitor his movements! The notch is suggestive, but there is another bit of evidence supplied by the French mentioned earlier that is far more compelling.

When the French team surveyed the Great Pyramid, they used microgravimetry, a technique that enabled them to measure the density of different sections of the pyramid, thus detecting hidden chambers. The French team concluded that there were no large hidden chambers inside it. If there was a ramp inside the pyramid, shouldn't the French have detected it? In 2000, Henri Houdin was presenting this theory at a scientific conference where one of the members of the 1986 French team was present. He mentioned to Houdin that their computer analysis of the pyramid did yield one curious image, something they couldn't interpret and therefore ignored. That image showed exactly what Jean-Pierre Houdin's theory had predicted--a ramp spiraling up through the pyramid.

Far from being just another theory, the internal ramp has considerable evidence behind it. A team headed by Jean-Pierre Houdin and Rainer Stadlemann, former director of the German Archaeological Institute in Cairo and one of the greatest authorities on pyramids, has submitted an application to survey the Great Pyramid in a nondestructive way to see if the theory can be confirmed. They are hopeful that the Supreme Council of Antiquities will grant permission for a survey. (Several methods could be used, including powerful microgravimetry, high-resolution infrared photography, or even sonar.) If so, sometime this year we may finally know how Khufu's monumental tomb was built. One day, if it is indeed there, we might just be able to remove a few blocks from the exterior of the pyramid and walk up the mile-long ramp Hemienu left hidden within the Great Pyramid.



A microgravimetry survey of the Great Pyramid in the 1980s yielded the enigmatic image at right. Less dense areas (indicated in green) seem to correspond to an internal ramp proposed by Jean-Pierre Houdin (diagram). (Dassault Systemes; Courtesy EDF) [LARGER IMAGE]

Bob Brier is a senior research fellow at the C. W. Post Campus of Long Island University and a contributing editor to ARCHAEOLOGY.

Pulley Reading: Bike Gears

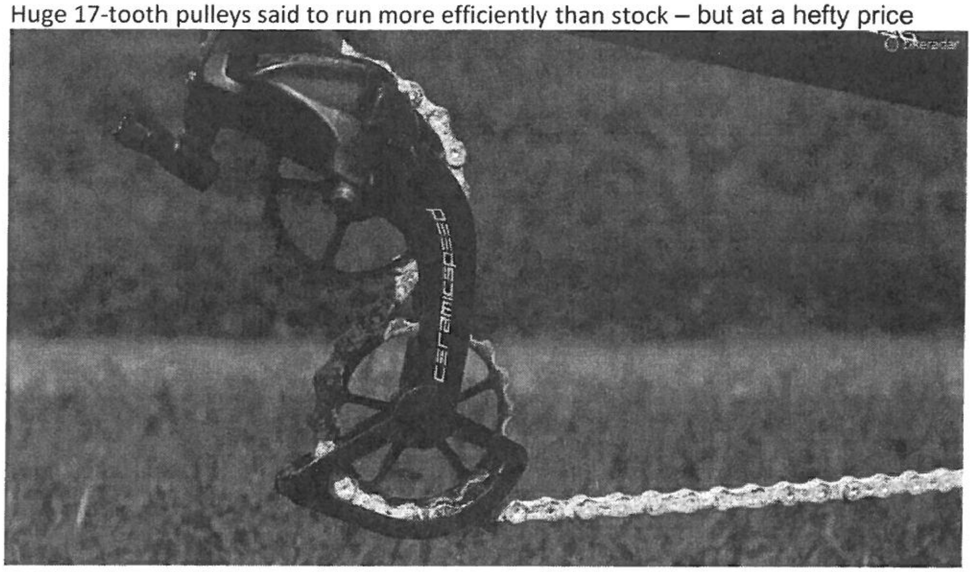
Monday, November 21, 2016 11:04 AM

Copied From: http://www.bikeradar.com/us/road/news/article/ceramicspeed-oversized-pulley-wheel-system-claimed-to-save-three-watts-45108/

CeramicSpeed Oversized Pulley Wheel System claimed to save three watts

By James Huang

Huge 17-tooth pulleys said to run more efficiently than stock – but at a hefty price



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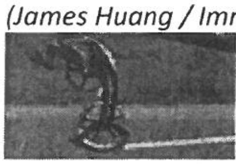
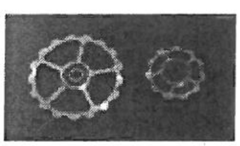
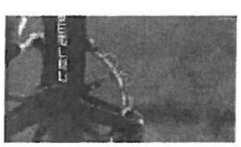
CeramicSpeed claims that its new Oversized Pulley Wheel System will save nearly three watts as compared to a standard Shimano Dura-Ace setup

(James Huang / Immediate Media)





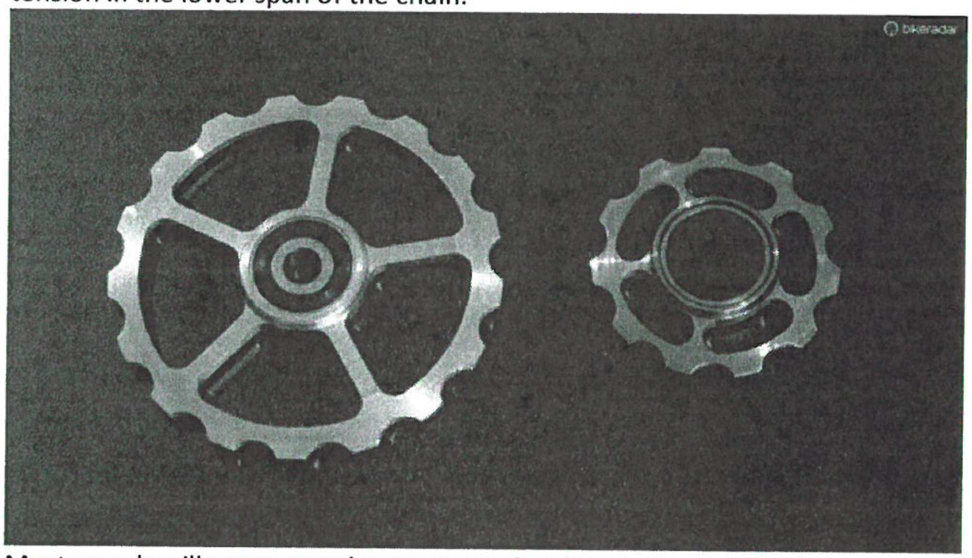


Danish bearing friction specialist CeramicSpeed is moving slightly outside of its comfort zone for its latest product: a complete rear derailleur pulley and cage assembly that the company says will save you up to 3W (based on a 250W output). The idea that bigger pulleys run faster is hardly revolutionary. The real question is how many folks will be willing to pay through the nose to get there.

CeramicSpeed outfits its new Oversized Pulley WheelSystem with two enormous 17-tooth pulleys that will supposedly save nearly 2.5W over a stock ShimanoDura-Ace 11-tooth setup – and that advantage apparently grows another half-watt when using a less-than-perfect chain.

Related: Check out more news from Eurobike at our Eurobike homepage

According to CeramicSpeed, this is because the larger pulleys force the chain to bend less (and more slowly) per link for the same given rider speed, the pulleys themselves spin slower, and there's less tension in the lower span of the chain.



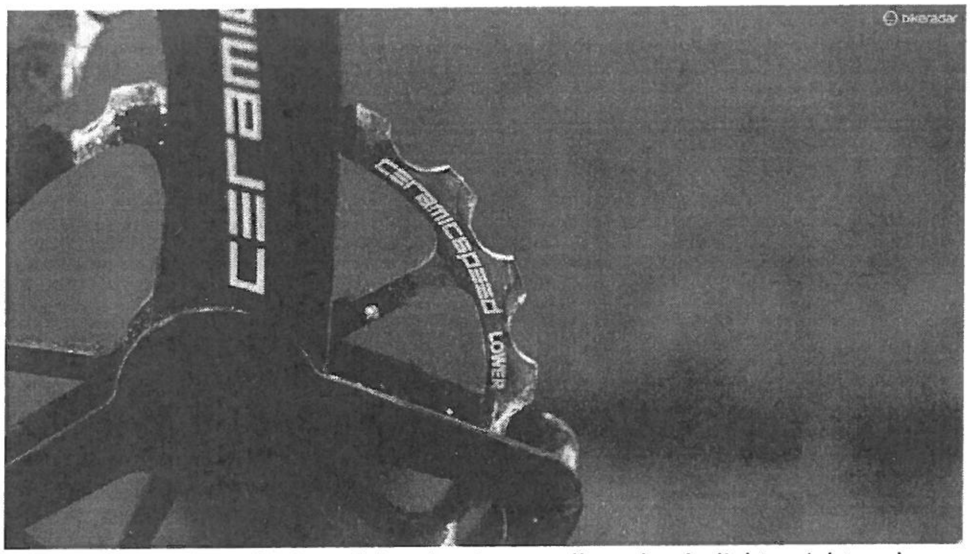
Most rear derailleurs currently use 11-tooth pulleys. ceramicspeed's new system uses enormous 17-tooth ones instead

As compared to typical 11-tooth pulleys (at right), CeramicSpeed's new 17-tooth pulleys look comically large

Naturally, CeramicSpeed also equips the machined-and-anodized aluminum pulleys with its own hybrid ceramic bearing cartridges, which are built with tighter tolerances than the ones used in the company's standard-diameter pulleys to better handle the increased side loading.

Despite the huge increase in pulley size, CeramicSpeed says that swapping to its OPWS assembly will only add 8-10g to a standard Shimano Dura-Ace rear derailleur. The cage plates are molded from lightweight carbon-reinforced polyamide plastic, and the pulleys are very liberally machined.

CeramicSpeed wouldn't divulge exact figures but the company also claims that there's essentially zero increase in aerodynamic drag with the bigger cage – at least when accounting for a realistically wide range of wind angles.



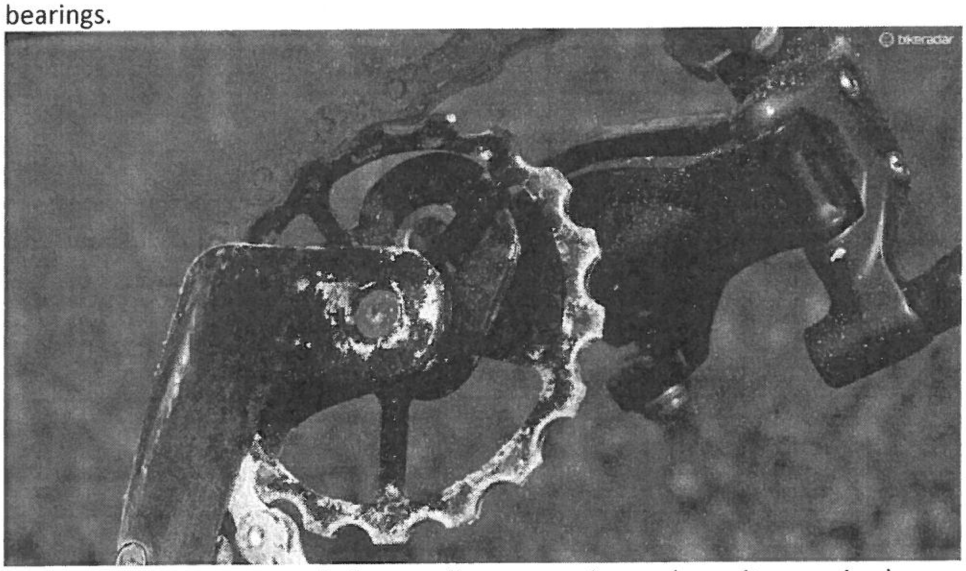
Thanks to liberal machining of the aluminum pulley wheels, lightweight carbon reinforced polyamide plastic cage plates, and titanium hardware, ceramicspeed says its new oversized pulley system adds just 8-10g over a stock shimano dura-ace setup

LIberal machining, lightweight carbon-reinforced polyamide side plates, and titanium hardware make for just an 8-10g weight penalty over stock

Thanks to the carefully designed cage geometry, an OPWS-equipped Shimano derailleur will accommodate cassette cogs up to 28-teeth in size – the same as stock – while supposedly making no sacrifices in shift performance, either.

CeramicSpeed says all of these friction claims have been independently measured by Friction Facts in Boulder, Colorado – the same lab that published the study on pulley size and drivetrain friction in 2013 that inspired the company to develop a complete pulley and cage assembly in the first place. Moreover, the latest round of testing has apparently confirmed that CeramicSpeed's new setup is now the fastest pulley system available, period, even beating out the widely heralded 13-15T Berner system often used by time trial and classics powerhouse Fabian Cancellara.

Not surprisingly, that sort of extra speed might be 'free' in the sense that you don't have to work any harder to get it but it's anything but free in terms of how much it'll drain your bank account. Retail cost for a complete cage and pulley assembly is a whopping $499 / €459 with CeramicSpeed's standard hybrid ceramic bearings, or an even more precious $600 / €539 with the company's even faster 'coated' bearings.



Despite the almost comically large pulleys, ceramicspeed says its oversized cage assembly will handle the same 28-tooth cassette cog as a standard shimano dura-ace rear derailleur

How much is extra speed worth to you?

CeramicSpeed is launching the system just for Shimano Ultegra and Dura-Ace 10-speed and 11-speed mechanical and electronic derailleurs for now, with production bits landing on store shelves some time around early October and SRAM-compatible versions to follow in later months.

The best way to go faster still is – and has always been – to train faster and better. But if you've reached your plateau (or just don't feel like working that hard), CeramicSpeed sure seems to have you covered.

For more information, visit www.ceramicspeed.com.

From <http://www.bikeradar.com/us/road/news/article/ceramicspeed-oversized-pulley-wheel-system-claimed-to-save-three-watts-45108/>

Pulley reading: Friction in Larger Gears

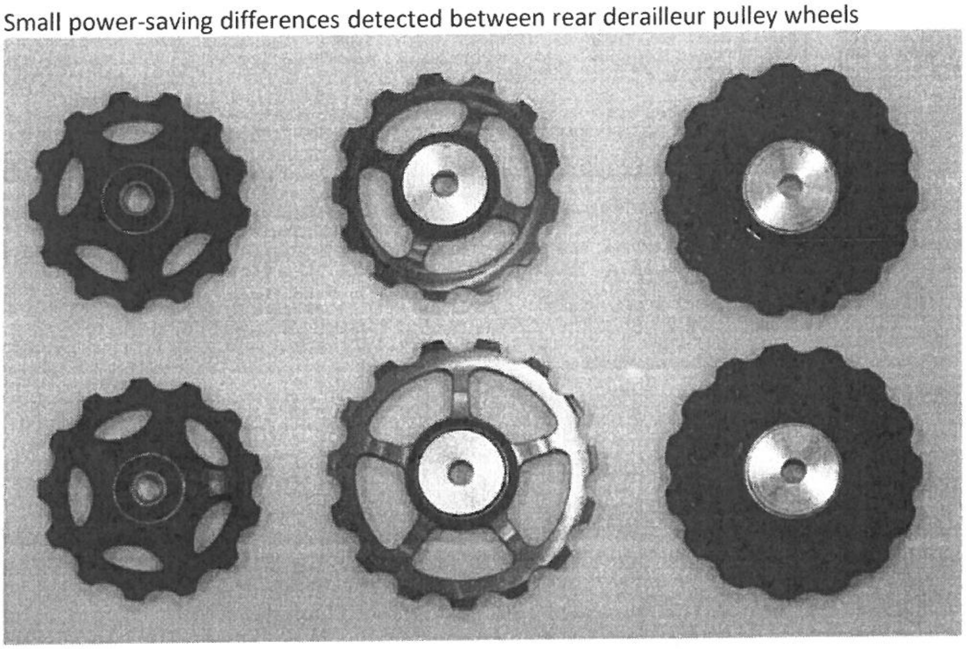
Monday, November 21, 2016 11:06 AM

Copied from: http://www.bikeradar.com/us/gear/article/friction-facts-bigger-pulleys-really-are-more-efficient-37615/

Friction Facts: Bigger pulleys really are more efficient

By James Huang

Small power-saving differences detected between rear derailleur pulley wheels



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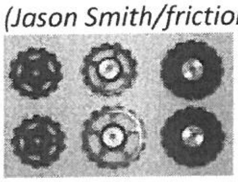
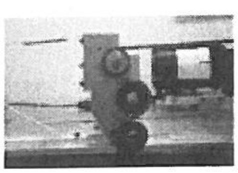
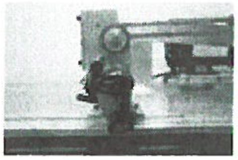
Among the pulleys tested were 13-tooth Shimano Dura-Ace 7700 (left), Berner's 13/15-tooth set (middle), and a pair of 15-tooth ones from RALTech (right)
(Jason Smith/friction-facts.com)



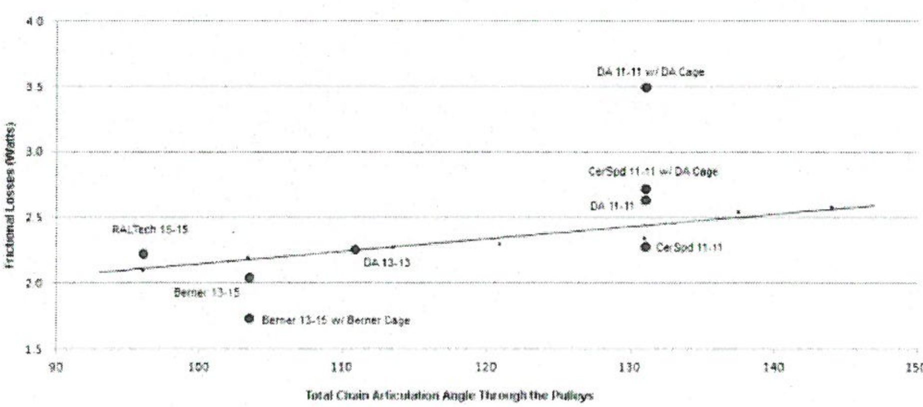




Pro road racers who use Berner's uniquely oversized rear derailleur cages have sworn time and again that they reduce drivetrain friction thanks to their humongous 15-tooth pulleys. Now, Jason Smith of Boulder-based lab Friction Facts has confirmed that claim with his own independent testing. Berner-equipped racers such asFabian Cancellara, Edvald Boasson Hagen, Philippe Gilbertand others will be relieved to know that the advantage is genuinely there – but it's also pretty small at just 1.76 watts compared to a standard Shimano Dura-Ace setup.

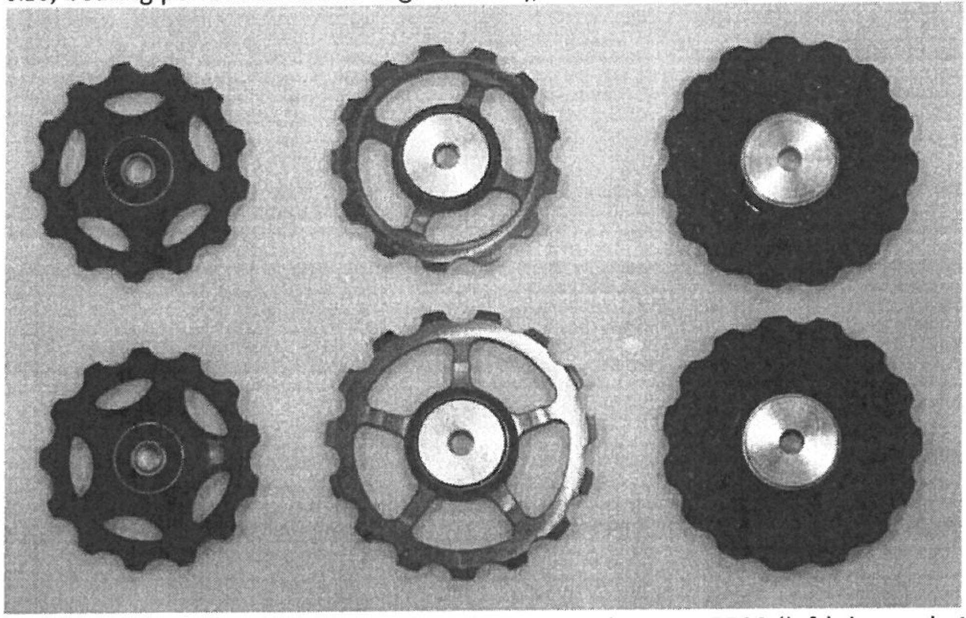
According to Smith, the Berner cage derives its advantages from three key principles: pulley size, cage tension and bearing friction.

Smith isolated the effects of pulley size by machining 10, 11, 13 and 15-tooth pulleys to the same bearing bore and then transferring the same two cartridges between tests. Lower chain tension (i.e., the chain tension between the lower rear derailleur pulley and the bottom of the chainring), cadence, and chainring and cog sizes were kept constant throughout testing.
The difference from best (15-tooth) to worst (10-tooth) was very small but still measurable at just 0.49 watts – similar to what others have calculated on theoretical terms. Comparing the 15-tooth pulleys to the 11-tooth ones more commonly used in modern derailleurs, the difference drops to 0.25 watts. Smith contends that the larger 15-tooth pulleys require the chain links to articulate less than with smaller pulleys as they pass through the cage, thus generating less friction between the side plates.



The results of friction facts' rear derailleur pulley and cage testing confirm the (slight) advantage of berner's oversized assembly. the x-axis displays watts while the y-axis displays total chain articulation angle: the results of friction facts' rear derailleur pulley and cage testing confirm the (slight) advantage of berner's oversized assembly. the x-axis displays watts while the y-axis displays total chain articulation angle*Smith's test results confirm a slight advantage to the Berner system. Lower watts (on the X axis) are*

better. The Y axis is chain articulation (how much the chain bends) through the pulleys
Subbing in the standard manufacturer's bearings – but still maintaining constant lower chain tension – extends that difference further, says Smith. A standard Shimano Dura-Ace 11/11-tooth pair of pulleys takes 2.6 watts of power compared to 2 watts on Berner's ceramic-enhanced 13/15-tooth setup.
Cage tension also apparently plays a role. In general, less tension is better than more. Smith says a stock Shimano Dura-Ace pulley cage creates 14.19N (3.19lb) of lower chain tension whereas a Berner's more lightly sprung setup creates less than half at just 6.85N (1.54lb). Taking all three factors in total (pulley size, bearing performance and cage tension), Smith measured a difference of 1.76 watts.

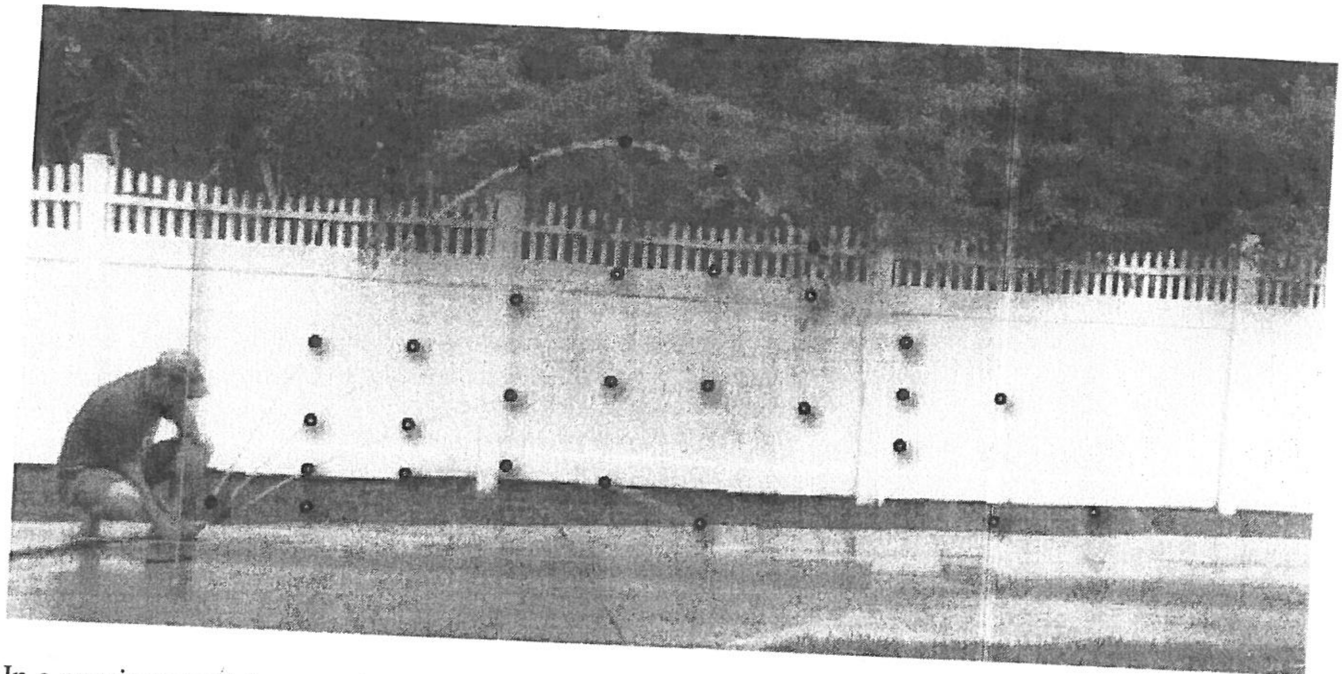


Among the pulleys tested were 13-tooth shimano dura-ace 7700 (left), berner's 13/15-tooth set (middle), and a pair of 15-tooth ones from raltech (right): among the pulleys tested were 13-tooth shimano dura-ace 7700 (left), berner's 13/15-tooth set (middle), and a pair of 15-tooth ones from raltech (right)*Among the pieces tested were (l to r) 15-tooth Dura-Ace pulleys, Berner's 13/15-tooth set, and a pair of 15-tooth pulleys from RALTech*
An efficiency gain of less than two watts is hardly earth-shattering for everyday riders and hardly practical when you consider that a ceramic-equipped Berner cage assembly runs about €359 (about US $478 or £305 at straight conversion rates). Two watts is still two watts, however, and for top-end pro riders and teams that rely on race results for their livelihoods, it's relatively "free" speed.
Regardless, Smith's results do have some more real-world implications such as the effects of a small-small vs. big-big gear combination, chain length (which would affect lower chain tension), and chain tension on singlespeeds and track bikes. Stay tuned for more.
Smith's full, detailed report is currently available as a free download at www.friction-facts.com.

From <http://www.bikeradar.com/us/gear/article/friction-facts-bigger-pulleys-really-are-more-efficient-37615/>

Water Hose Projectile Motion

- By Rhett Allain
- 06.25.13



In a previous post, I was trying to show that the range of a projectile depends on the launch angle. Yes, this isn't that too difficult to see in an introductory physics course, but how do you show this to kids? My idea was to do something from my book *Angry Birds Furious Forces*. In that experiment, I built a small Lego-based projectile launcher.

However, is there a simpler way? What about a water hose? In the composite image above, I spray the hose at different angles and you can see that it has different ranges. Ideally, the greatest range should be for water launched at a 45° angle. Why?

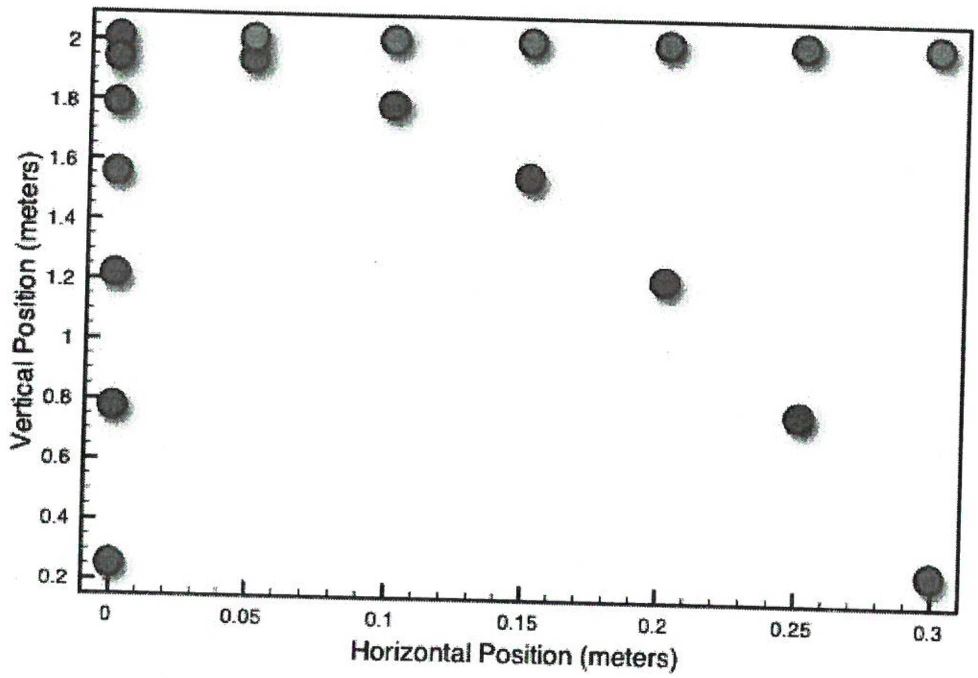
First, let's assume that a piece of water in the stream has only one force acting on it after it leaves the hose. That one force is the gravitational force and it pulls straight down. But what does this do to the motion of the piece of water? If we look at the simple case of water shot straight up, it can give some insight. Since the water is moving up but the force of gravity is down, the water will slow down as it rises and then stop and fall back down and speed up. The faster it starts out moving vertically, the longer it will stay in the air.

What if the water was only moving horizontal? Maybe the piece of water is launched horizontally on some frictionless track. In this case, there is no force acting on the water after it leaves the hose which means no CHANGE in motion. The water would just move horizontally at a constant speed.

Now if you put this vertical and horizontal motion together at the same time, you get projectile motion. The key to projectile motion is the idea that the vertical motion and the horizontal motion are essentially independent of each other. You can try a very simple (and fun) experiment.

Set a book on the edge of a table so it is just about to fall off. Now get another book and slide it so it barely collides with the book on the edge. What should happen is that both books will fall off the table at the same time but with different horizontal speeds. However, since both books start at the same height with the same vertical speed (zero), they will hit the ground at the same time.

This shows that the motion of a book launched off a table is a combination of vertical and horizontal motions. The horizontal motion is at a constant speed and the vertical motion accelerates. Here is a diagram that shows this idea.



The red dots show the motion of a ball. The green dots show the motion of a ball with the exact same horizontal speed as the red ball. Finally, the blue dots show a ball with the same vertical motion as the red ball.

But what does this have to do with range? I'm getting there. I assume that the starting speed of the water is the same no matter what angle it is launched at. So, how do you make the water go the farthest? One idea would be to shoot it completely horizontal. In this case, all of the speed of the water would be in the horizontal direction. However, it wouldn't go very far. Why? Because the water wouldn't be in the air for any significant time. You need to keep the water in the air for as long as possible.

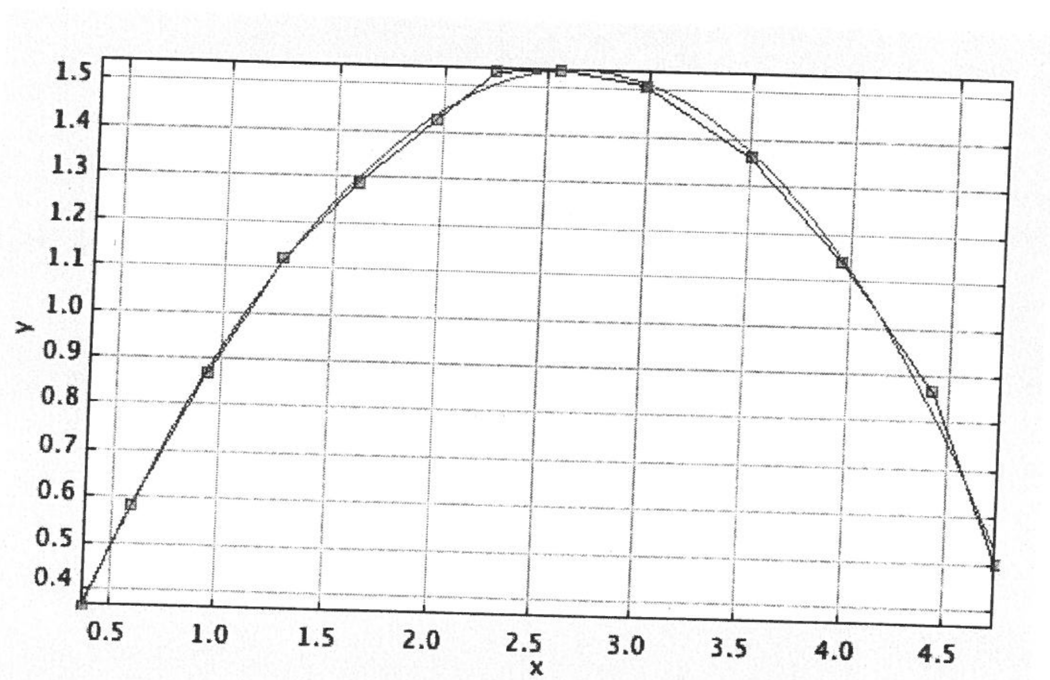
Well, then you could shoot the water straight up. That would keep it in the air for the longest time. True. However, in that case there would be no horizontal component of the water's velocity so it wouldn't go horizontally at all. There needs to be some balance between time in the air and horizontal motion. That balance happens to be at a launch angle of 45°. Here is a much more detailed derivation of this maximum range.

One warning. This maximum range at an angle of 45° is only true if there is no air resistance and the object is launched from the ground and back to the ground (no height change from start to finish). But that is what I am trying to show with the water hose. If you shoot it at too high of an angle, it doesn't go too far.

Is the Path a Parabola?

Maybe I should have looked at this part first. Does the path of the water even make a parabola like a projectile motion object with no air resistance would? Let's find out. This is a little more complicated than looking at stream of water, but it isn't too bad. In order to get a trajectory for the water, I am going to use a video analysis program, Tracker Video. Yes, it's for videos but it will work with images also.

Looking at one of the streams, here is the plot of horizontal vs. vertical position – I had to guess a little bit on the dimensions in the video.



Fit Name: Parabola | Fit Builder...

Fit Equation: y = A*x^2 + B*x + C

Autofit | rms dev: 1.629E-2

Parameter	Value
A	-0.227
B	1.198
C	-0.038

A parabola sure seems to fit. What about the fitting equation? I derived the trajectory equation in a previous post, so I will just list it here.

$$y = x\left(\frac{v_{y0}}{v_{x0}}\right) - x^2\left(\frac{g}{2v_{x0}^2}\right)$$

The coefficient in front of the x^2 term depends on the gravitational field (g) and the horizontal velocity of the water. For the trajectory above, there is an x^2 coefficient of -0.227 m^{-1}. Going back to the image, I get an estimated launch angle of about 41°. From this, I can solve for the launch speed of the water.

$$-0.227 \text{ m}^{-1} = -\frac{g}{2v_{x0}^2} = -\frac{g}{2v_0^2\cos^2\theta}$$

$$v_0^2 = \frac{g}{2(0.227 \text{ m}^{-1})\cos^2\theta} = 39.897 \text{ m}^2/\text{s}^2$$

$$v_0 = \sqrt{39.897 \text{ m}^2/\text{s}^2} = 6.156 \text{ m/s}$$

A water speed of 6.1 m/s seems reasonable (about 14 mph). But overall, I think this water stream is mostly like the trajectory of a an object in projectile motion.

If you want, you can take that image with the water streams and look at all of the water paths. Fit a parabola to each one and then find the initial water speed. They should all be near the 6.1 m/s value. You can consider that to be your homework.