intel
FUTURE SKILLS

Game of Chance

PROJECT OVERVIEW: LOW-TECH PROBABILITY PRIMER

Build a low-tech Galton board to help visualize probability (chance). Then, expand your exploration by removing or adding pegs to create different probability curves.

PROJECT CATEGORY:
Quantum

DIFFICULTY LEVEL:
Intermediate

TIME RANGE:
45 - 90 minutes

GROUP SIZE:
2 - 4

ESSENTIAL SKILLS AND MINDSETS:

Iteration

Prototyping

Simple Machines

Collaboration

Embracing Your Mistakes

Dream It!

In this project, you will get hands-on with probability by building a device of chance that sorts round beads into a binomial distribution curve (also called a bell curve). You will not know for certain where each bead will end up, but you will always get a predictable curve. This is due to the probability (chance) of each bead bouncing left or right while traveling down your device. (For reference, this tool is called a Galton Board or bean counting device.) You can learn more about its unique names later on.

1.

To start, watch the Galton Board Introduction Video and the Quantum Probability Videos to learn more about probability—including how it relates to quantum computing. [:05]

2.

Now, read the Explore More: The Magic Behind Pascal's Triangle section to get a better understanding of binomial distributions and the math behind a Galton board. [:05]

EXPLORE MORE: THE MAGIC BEHIND PASCAL'S TRIANGLE?

It's amazing how you can use a simple idea like Pascal's Triangle to solve complicated problems such as probability and advanced mathematics.

What does Pascal's Triangle look like?

Here's how it works: The top of the triangle is always 1. The second row below it is always (1, 1).

Remember that the third row—and every other row—starts with 1 as well. To calculate the next number, you simply add the two numbers from the top row starting from the left (1 + 1 = 2). When all the numbers from the top row have been added, you will end with a 1. This means the second row becomes (1, 2, 1).

From there, you will want to do the same thing for the third row so that your triangle looks like:

(1, (1+2), (2+1), 1) or (1, 3, 3, 1)

Then, simply continue. The bigger you make the triangle, the more problems you can solve.

AT-HOME SUBSTITUTIONS:

In a pinch, you can use a cardboard box instead of foam core for the back of the Galton board (thick foam is best for larger boards). Or, if you really want a fun challenge, try to make a Galton board out of LEGOs—using the round "dots" instead of marbles or beads!

DID YOU KNOW:

Lots of things in nature follow a normal (or binomial) distribution:

People's heights, shoe sizes, etc.

What else can you think of that might follow a normal distribution?

TOOLS AND MATERIALS:

Low-Tech Galton Board:

- Printed Galton board templates **tiny.cc/galtontemplates**
- Pencils, bamboo skewers, nails, pushpins, etc. (50 total)
- Recycled materials
- Hard foam or foam core sheet (8.5 inches x 11 inches or larger)
- Marbles or beads of various sizes (1/4 inch or 6mm work best)
- Large tongue depressors

MATERIAL PURCHASE LINK:

http://tiny.cc/Intelbuylist

PROJECT INTRO VIDEO:

- What's a Galton Board? **http://tiny.cc/galtonboard**

QUANTUM PROBABILITY VIDEO:

- Galton Explained **http://tiny.cc/galtonexplained**

3.

Design your Galton board:
Now it is time to design your board! Use the Think About It section to guide your ideas. Then, when you're ready, jot down the answers to each question. [:05]

THINK ABOUT IT

Your end goal is to build a device that will make different probability curves. You will want your device to be changeable—or hackable, if you will. To that end, consider the following questions as you start to build a board that you can continually change (iterate) as you test different probability curve hypotheses.

What materials will you use?

Where will you source the materials?

What is your total time and materials budget?

How will adding or removing pegs change the probability and curve of your device?

How can you easily test various hypotheses? How can you make your device manipulatable (i.e., moveable pegs, other features, etc.)?

A DASH OF DESIGN THINKING

Design thinking is a system that helps to solve problems using iteration and prototyping. Watch our video to learn how you can use design thinking as you start to build a new Galton board-inspired probability device that can be tweaked, changed, and rebuilt as you iterate.

Intel Design Thinking Explained
youtu.be/NTmXw40wmjU

4.

Draw your Galton board idea(s), labeling all the parts using the space at right. [:05]

List your materials here:

REMEMBER:

Your materials will vary based on the size and style of your Galton board idea. To start, we recommend using the 8.5-inch x 11.5-inch Galton board template, pushpins, and beads; however, if you'd like to design a smaller or larger version, go right ahead. Just make sure you have enough time and space to build a board that you are proud of! Also, remember that to get a nice probability curve, you will need to be precise. Go as slow as you need, and make sure you are specific so that you don't skew your binomial distribution.

Build It!

5.

Collect your materials and get ready to build your new probability device (Galton board). [:05]

NEED SOME HELP?

If you having a hard time getting started, feel free to use our downloadable templates and step-by-step build guide located on the next page.

PRO-TIP

- Design and build your device to create a binomial curve first. Make sure it works, and then hack/tweak it to create different curves.
- Precision is key! Make sure everything is straight and spaced consistently.
- In your design, make sure to consider both the form and the function of the board. Areas to consider include:
  - Thick foam vs. basic cardboard or cardboard box
  - Peg size (nails, pushpin, etc.) vs. gap size (how much space is needed to make sure the bead fits through)
  - Ball or bead size (in relation to the peg and gap size)
  - The angle of your board's incline
  - The starting location of your beads/ball (i.e., Is it directly over your first peg?)

6.

Build your first iteration of your Galton board. [:20]

QUANTUM COMPUTING FUN FACT

Quantum computers can solve real-life problems that take a long time. This means a quantum computer can help predict the weather or improve pharmaceutical drugs, computer security, and even the economy.

Changing Pascal's Triangle probabilities with quantum computers:
Using Pascal's Triangle, we can see when flipping a coin once the probability of flipping heads is 0.5 and the probability of getting exactly two heads in four tosses is 0.375. Quantum computers can change that probability to 1 or close to 1 for really hard problems. That's why it's faster than classical computers.

How quantum computers change the probability curve?
It does this by shifting the probability curve to a straight line centered around the outcome you want to happen. In our example of getting exactly two heads in four tosses, the probability curve now reads (0, 0, 16, 0, 0). All the possible outcomes now happen at the third column.

GOING DEEPER WITH QUANTUM COMPUTING:

Take a look at how Intel is using quantum mechanics and technical know-how to make the quantum chips of the future.

Intel, How Quantum Computing will Answer Unsolved Problems
http://tiny.cc/intelquantum

HOW TO BUILD A GREAT GALTON BOARD:

Still need help building your board? If so, follow the general steps below to get started fast!

1. **Pick your backing board.**
   We like flat cardboard boxes, foam core, cork, and other soft materials that are at least 10 inches x 14 inches, and thick enough for pushpins (pegs) to push in completely.

2. **Choose your peg material.**
   Pushpins and nails tend to be the easiest to use—but you could also try toothpicks, bamboo skewer segments, or even small dowels.
   Remember to make sure whatever you use for a peg is solid and doesn't wiggle too much when the balls/beads bounce off of it.

3. **Print out a Pascal's Triangle template.**
   We have a variety of templates you can use, and they are all based on Pascal's Triangle. (See the callout box on Pascal's Triangle for more detailed information.)
   Download templates using the link below. The templates are each different in spacing and size, so try each one to see which works best for your bead/marble size. **https://tiny.cc/galtontemplates**

4. **Put your template at the top of your backing board, tape it in place, and start inserting your nails, pegs, and pushpins into the center of the hexagonal area.** (We like pushpins the best as they make a very solid peg.)
   Continue until all of the triangle's hexagonal areas are full.

5. **Add your dividers (i.e., popsicle sticks, flat pieces of thin wood, sturdy cardboard strips, etc.).**
   At the bottom of the Pascal's Triangle, start putting your dividers in place. (Follow the lines on the template to make sure they are evenly spaced.)
   Hot glue is the easiest way to attach your dividers, but you may also want to try pushpins, T-pins, or other fastening techniques to hold your dividers in place.
   Make sure that you also have some sort of divider at the bottom of each column separator to hold the balls in place. This can be removed when you are done testing, allowing you to retrieve your balls/beads.

6. **Create a funnel at the top of the triangle, directly over the first two pegs**. (This will help deliver many beads simultaneously. See the sample video to get a better understanding of what this might look like.)

7. **Test out different-size beads, balls, or marbles to see which ones bounce through your Galton board the best.** Make sure your board is nice and level for the test.

8. **Now, tweak, test, change, iterate, and repeat to make your Galton board even better—or to produce different curves.**

9. **Congrats! You are done.**

DID YOU KNOW?

Pascal's Triangle and computing power

You can use Pascal's Triangle to figure out the computer power of bits or qubits.

Every time you add a bit or qubit, you count the rows down the triangle and add the columns to give you the total number of storage.

For example, if your computer had 4 bits or qubits, just count down 4 rows on the triangle and add the columns. Remember start from the 0 row and column. You can see that there are 16 possible different ways to store information (1+4+6+4+1).

The big difference is a classical computer with 4 bits can only use 4 pieces of information at one time, while quantum computer with 4 qubits can use all 16 pieces of information at the same time.

Every time you add a qubit, you double the quantum computer's power. A quantum computer of just 30 qubits, is more powerful than any supercomputer ever built. Just think how powerful a 100, 500, or 1000 qbit computer may be in the future? The potential processing power is amazing!

7.

Test different bead sizes, nails or pushpins (or other pegs), and your bead start/drop location (as well as different funnel or bead delivery devices). [:10]

List out 5 ideas for that you should test (beads of different sizes, new pegs, etc.).

8.

Based on what works and what doesn't, iterate to make your Galton board device even better. [:15]

List what iterations you have tried and how they have worked.

9.

Once the Galton board function works well (making a nice binomial curve), you can start to change it to create new probability curves. For example, you can explore what happens if you take out one or more pegs/pins from the Pascal's Triangle. Hypothesize and test different patterns to see what occurs. [:15]

Write down 3 ideas on how you could change your Galton board to make a different curve as well as what you think will happen based on each change.

DID YOU KNOW?

Did you know: Governments make decisions that can affect transformative technologies like quantum computing. Intel encourages governments to make rules that support global distribution, development, and use, which is essential to allow technology growth.

Find more on Intel's public policy here: **tiny.cc/intelpolicy**

Will quantum computers replace classical computers?
No. You need a classical computer to interface with a quantum computer—meaning you will always use a classical computer to play video games, write stories, and do other common activities.

Share It!

10.

Show off your probability device to a friend, group, or family member in order to get feedback on it. [:05]

11.

Clean up your workstation, and keep thinking of new ideas to make your device better. You could work on making it bigger, smaller, or even have it make a double curve. Think about what other ideas you would like to test out, and discuss your options with the group to plan your next experiment! [:05]

Expand It!

Want to take your probability board to the next level? Try some of these ideas to make it bigger, smaller, automated, or anything else!

- Make an electronic (auto-count) version of a Galton board using Arduino
- Use this tutorial to create an Arduino-driven sensor that automatically counts and displays the balls as they exit the bottom of the device.
  For example: **youtube.com/watch?v=t_IXjyOo-PA**
  Or any of these: **youtube.com/results?search_query=object+counter+arduino**
- Want a smaller Galton board? Look at this desktop-manufactured Galton board and see if you can make one even smaller: **youtube.com/watch?v=EvHiee7gs9Y**
- Want to go big? Take a look at the Boston Museum of Science's huge Galton board, which takes up a whole wall: **https://youtu.be/wUgQtXEodf0**
- How about 3D-printing your own Galton board? Here's a great tutorial, and a printable .STL file too: **instructables.com/3D-Printed-Galton-Board**
- Here is an awesome tutorial on how to build a nice wooden marble-sorting Galton board (featured in a very detailed and well-done guide): **karlsims.com/marbles**
- Make your own probability game using this math mini-unit to explore even more: **tiny.cc/probabilitygame**

HELPFUL RESOURCES:

- Galton Board Project Reference Links and Videos:
  Basic Board Video: **youtube.com/watch?v=6YDHBFVIvIs**
  Make a Basic Paper Galton Board: **abakcus.com/diy/how-to-make-a-galton-board**
- The Math Behind a Galton Board: V-Sauce Video: **youtube.com/watch?v=UCmPmkHqHXk**
- Quantum Computing Basics Webpage:
  science.org.au/curious/technology-future/quantum-computing
- Quantum Computing Explained: **youtube.com/watch?v=JhHMJCUmq28**
- Pascal's Triangle Explained: **brilliant.org/wiki/pascals-triangle**
- Lecture on Quantum Probability: **youtube.com/watch?v=wWZyLGEqgio**

NEED HELP OR MORE INFORMATION?

Contact us at:
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This Intel Future Skills project guide was developed as part of the Q12 Initiative.

Launched by the White House Office of Science and Technology Policy and the National Science Foundation, Q-12 is a consortium that will expand access to K-12 quantum learning tools and inspire the next generation of quantum leaders.

For more information visit:
https://q12education.org

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