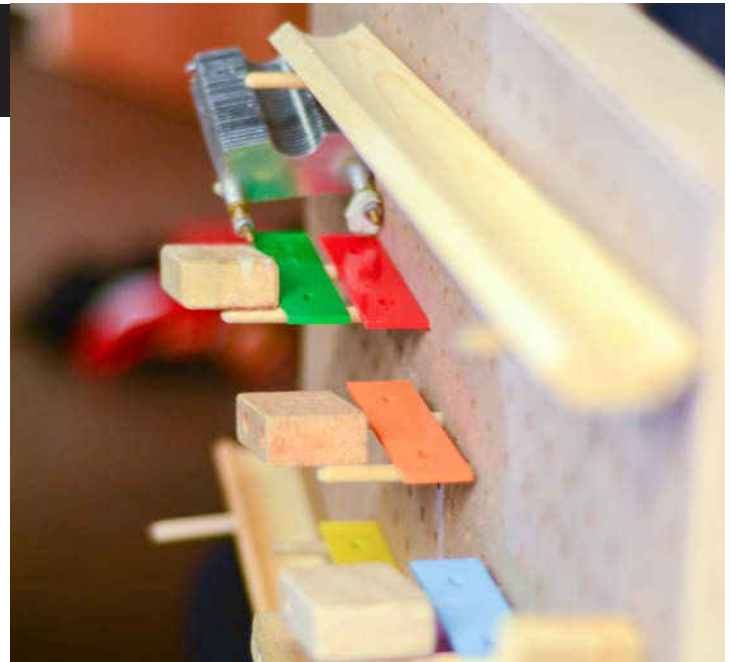


# MARBLE MACHINES

A Marble Machine is a creative ball-run contraption, made from familiar materials, designed to send a rolling marble through tubes and funnels, across tracks and bumpers, and into a catch at the end.

Building a Marble Machines pegboard wall is the first step. The addendum to this guide includes step-by-step illustrated instructions to help you create a marble board. Once you have the board ready, you can focus on the main activity - building your own Marble Machines.



## TRY IT!

### Interesting materials to collect:

Once you have made your marble board, you can use all sorts of interesting materials to construct a ball run for your marble. Cups or bowls to hold marbles, bells or metal objects for sound, string, Dixie cups, straws, springs, metal ball bearings, foams, mesh, cardboard, pipe cleaners, and anything else that may be helpful in building.

the  
tinkering  
studio

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# GETTING STARTED

**Your goal is to make the marble travel from the top of the board to the bottom as slowly as possible.**

The cove moulding can be placed on the pegs and used as tracks to guide the marble to the destination. Experiment with different angles to get different speeds.

Tape helps! Once you get a part of your machine working the way you want add a bit of tape to keep the parts secure. Clothespins can also help keep parts in place.

The bumpers can be held securely in place or can swing freely. Either way they help to control the marble on its path.

The broccoli bands can be used for multiple purposes. We tend to use them to hold pipes against the board or use them as trampolines



Here are some other challenges to try after building your first machine:

- Try to make the marble go uphill
- Try building multiple pathways. Can they all lead to the same place, or different destinations?
- Try using both sides of the board.
- Can you build away from the board and return to it?
- Think about using sacrificial marbles. Start with one marble that does its job then triggers or releases another, then another.
- Marble elevators are a classic design challenge.
- Use Foamies or mesh, or construction paper to build unexpected structures.
- Think about a theme for the board and use materials that are all one color, map a path through your home town, or tell a story.

# TAKE IT FURTHER

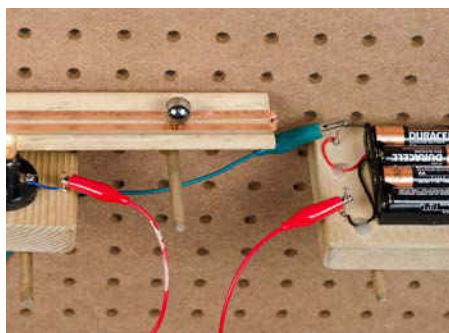
Add keys, bells, xylophone keys, chimes or other metallic objects and pay special attention to the sounds created when the marble strikes the materials. See if you can create a marble based musical composition.

Incorporate electronic mechanisms and decorations into your marble machines. Using metal bearings for marbles and tinfoil, you can create switches to activate motors or LEDs on your board.

Build your own elements or modify what you have collected to create a custom set of materials. You may add sandpaper, speed bumps, or cloth to the tracks to slow the path. Find some woodworking tools and build your own plinko board, see saws, or switchers to add to your collection of parts.



Marble Machines



tinkering.exploratorium.edu





# EDUCATOR ADDENDUM

## **A note on our philosophy:**

*The Tinkering Studio is based on a constructionist theory of learning, which asserts that knowledge is not simply transmitted from teacher to learner, but actively constructed by the mind of the learner. Constructionism suggests that learners are more likely to make new ideas while actively engaged in making an external artifact. The Tinkering Studio supports the construction of knowledge within the context of building personally meaningful artifacts. We design opportunities for people to “think with their hands” in order to construct meaning and understanding.*



## **Activity Design** (decisions and designs that support a tinkering experience)

*Tinkering Studio activities and investigations are designed to encourage learners to complexify their thinking over time. The variety of materials and variables available for experimentation allow learners to enter at a point where they are comfortable starting, and then alter and refine their designs as they develop new ideas. Tinkering activities are often fun, whimsical, inspired, and surprising.*

Building a Marble Machine is a playful platform for the learner to investigate concepts at the intersection of art, science, and technology. The process of testing, questioning, and occasionally failing is as significant as the final construction. Here are a few principles that exemplify the design goals of this activity:

- STEM (science, technology, engineering, and mathematics) education is a means, not an end in itself. Careful observation and responsive engineering is at the heart of this activity. Participants are intrinsically motivated to address a multitude of shifting engineering challenges while they build their marble machine.
- Activities and investigations encourage learners to complexify their thinking over time. The variety of materials and variables available for experimentation allow for learners to rebuild and redesign as they have new ideas. Complexity can manifest itself structurally (by experimenting with a range of materials, techniques, and systems), aesthetically (by limiting materials or adding color, sound, or patterns), or even socially (by collaborating across boards and sharing ideas which expand possibilities).
- Activity station design enables cross-talk and invites collaboration. Marble Machines are built at individual boards which are portable and can be combined, or on large communal walls that allow for participants to see, hear, and incorporate what others are working on. Solutions to similar problems are shared and iterated upon from one builder to the next.

## **Environment** (the elements of the space that support tinkering)

*In the Tinkering Studio there are many things we keep in mind when setting up an environment for a tinkering activity. We hope that learners will be working with us for an extended period of time, so we try to create a warm and welcoming workspace with comfortable seating, sturdy worktables, and good lighting. Displaying examples from past projects and current activities throughout the space can help to seed ideas and inspiration, as well as provide an introduction to what is happening that day. We often set up large, communal activity stations to enable cross-talk and invite collaboration between participants, allowing them to look to each other for answers and solutions. Materials are easily accessible to see for inspiration and use for construction as needed when building. We may also place exhibits or activities related to a similar theme nearby to encourage cross-pollination of ideas through adjacency. These are general ideas that we use at the Exploratorium, but could apply or be adapted to many different settings.*

When creating an environment for Marble Machines, you'll want to prepare areas for materials and building. Creating space around the boards is also important because this is a physical enterprise where participants are often kneeling, sitting, standing, or just stepping back to reflect and watch their creation. There is a back and forth between building and reassessing possibilities, so you may want consider how participants will move from their boards to the materials area. Creating a central materials table ringed with boards helps create a communal space with equal access to materials and quick visual connections to other participants and their boards.

Try the activity beforehand to discover what materials work well for you. Once you've found a good set, consider how you'll want to display them to make them visible and accessible for the participants. We've used cafeteria trays, large bowls, and paint buckets to arrange the materials on a table in the middle of a classroom. For the museum floor we created more durable carts with places for each material.

A carpeted area helps keep errant marbles under control. Having an enclosed environment makes this much easier. If working on a larger open space, we found that a garden hose around the space (clearly marked and taped down) can keep marbles from going astray.

Good lighting is critical when keeping track of tiny marbles rolling through a maze of materials so make sure the light is bright and even.



### Facilitation

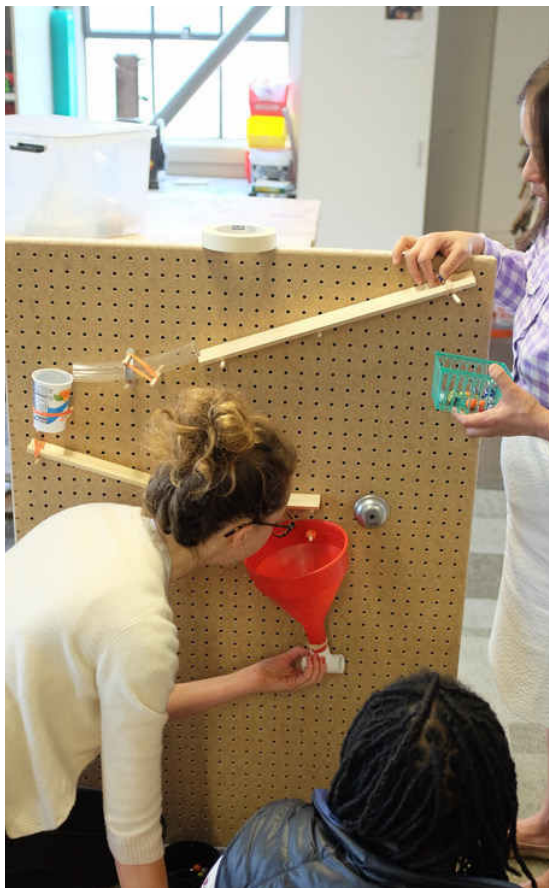
Facilitation is a way of teaching where you support the learner's own investigations, questions, and ideas within the framework of an activity. In the Tinkering Studio, we strive to practice a type of facilitation that respects the individual path of each learner. As facilitators, we watch and wait until the precise moment to jump in and offer a hint, a material, or a new way of looking at a problem. As educators, we allow learners to feel frustration and encounter moments of failure as they work with real materials to try to solve their own challenges.



There are many ways that the facilitator can influence the interactions with participants in an activity. We help people get started with the activity by giving a quick sense of the goals. We introduce the materials or tools they might use and invite them to their own space. We spark interest and sustain learners' engagement by asking questions about their work and responding to their answers. We support multiple outcomes of the activity and are open to the possibility of new ideas, different solutions, and changing goals of the individual learner. We try to practice a style of facilitation where we are not teachers who transmit knowledge to a passive learner, but rather are guides or co-learners on a path to understanding.



For Marble Machines there are a few things to keep in mind as a facilitator. The first prompt you might offer a participant is to try to get the marble to descend as slowly as possible. Given the speed and unpredictability of the marbles this challenge is often a good way to get started. Often the prompt is soon forgotten as they get involved and engaged. It is better to offer the prompt as an option and not a rule. We don't time the marbles at the end and we're not interested in fostering competition. We value each individual's process and unique ideas.



Encourage testing early and testing often. There can be a temptation to build the entire marble run without testing and surprises will start on the very first track. Testing as you go allows a dialogue with the activity and the feedback helps inform new directions and ideas.

At its heart, Marble Machines is about careful observation. The path of the marble is predictable enough to give you a sense of what to do next to guide its path, but this requires observation, resourcefulness, and playful experimentation.

As a facilitator you can ask participants to show you how their Marble Machine works. This can give you some insight into their process and intentions. Explaining their own work can also help them identify trouble spots.

Keep in mind that offering materials and suggestions is preferred to actually stepping in and making changes for them, particularly when they might be reaching a point of frustration. These moments are significant when the solution finally emerges from the process. On that note it is important to allow people to pursue expansive and difficult ideas that may not seem to be viable initially. The thresholds of this activity are there to be explored and, more often than not, reaching for them leads to remarkably creative and original ideas. When imagination is encouraged new ideas flourish and the activity grows. The ability for Marble Machines to be “complexified” is one of its great strengths.



The social environment also plays a key role. It is important to encourage the sharing of ideas. The physical layout of the space can help with this. It is great to walk around and see novel solutions to problems similar to the ones you might be facing. Often an idea will spread and participants will be riffing off a particular theme or strategy, like marble elevators, rubber band trampolines, or loop de loops.

There is always more that you can do, so it's important to emphasize that this is a process and not necessarily about “finishing.” During a sharing session you can ask people to show what they've done so far and what they might be planning to do next. Questions like “What would you do if you had 2 more hours?” can help reinforce this notion of process over product.

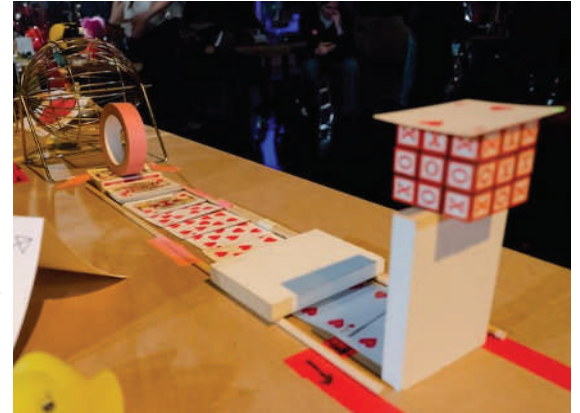
# RELATED TINKERING ACTIVITIES

## Activity Connections

Try these related activities to develop your own repertoire of tinkering experiences.

**Chain Reaction:** Chain Reaction takes the vertical experience of building a marble machine and moves into a three-dimensional space. In a chain reaction, each participant gets a chunk of real estate on a table to build a sequence of events that will connect with a contraption built by the next participant. Marble machines can provide a good introduction to the activity because through building a course for the marble you build up the practice of testing and observing. Because of this quality of experience, marble machines is often the first activity we present to a group to show the process of tinkering that can be developed through other activities.

[tinkering.exploratorium.edu/chain-reaction](http://tinkering.exploratorium.edu/chain-reaction)



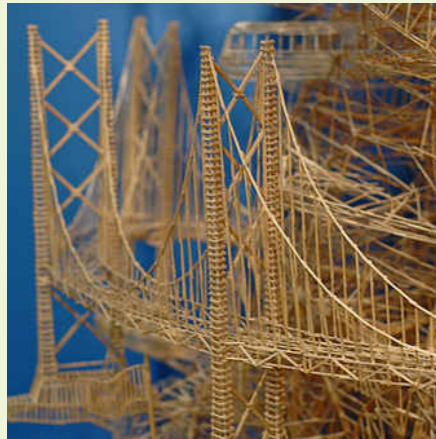
## ARTIST CONNECTIONS

*(inspiring connections to the Scribbling Machine activity)*



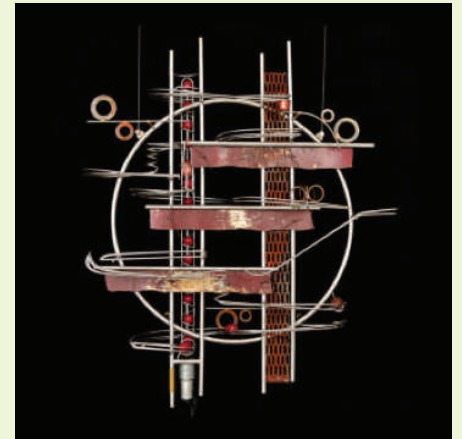
**Bernie Zubrowski's** book *Raceways: Having fun with balls and tracks* was the inspiration for *Marble Machines*. He is a Senior Scientist for Education Development Center, Inc. (EDC), who has spent much of his professional life devising ways to educate young people about science, both while they're at school and when they're out in the world, away from the classroom. He has contributed to many landmark science curricula, including Elementary Science Study and the African Primary Science Program.

[zubrowskib-sculpture.com](http://zubrowskib-sculpture.com)



**Scott Weaver's** family has lived in San Francisco for 3 generations. Scott started building toothpick sculptures in 1968, when he was 8 years old. Early structures were abstract and about 2–4 feet tall. Then he built one sculpture that had a ping-pong ball roll through it. In 1974, Scott started a new sculpture and added the Golden Gate Bridge and Lombard Street, which also had a ping-pong ball roll through it. This is what started what is now *Rolling Through the Bay*.

[tinkering.exploratorium.edu/scott-weaver](http://tinkering.exploratorium.edu/scott-weaver)



**Jeffrey Zachmann** is a kinetic sculptor who specializes in metal marble contraptions that are beautiful as well as functional. "I see my work not simply as sculptural machines, but also as studies in line, shape, color and motion. I find the biggest challenge with my work is balancing technical structure with artistic need. My goal is to make my sculptures intriguing static pieces that, when set in motion, become captivating."

[www.zachmann.com](http://www.zachmann.com)

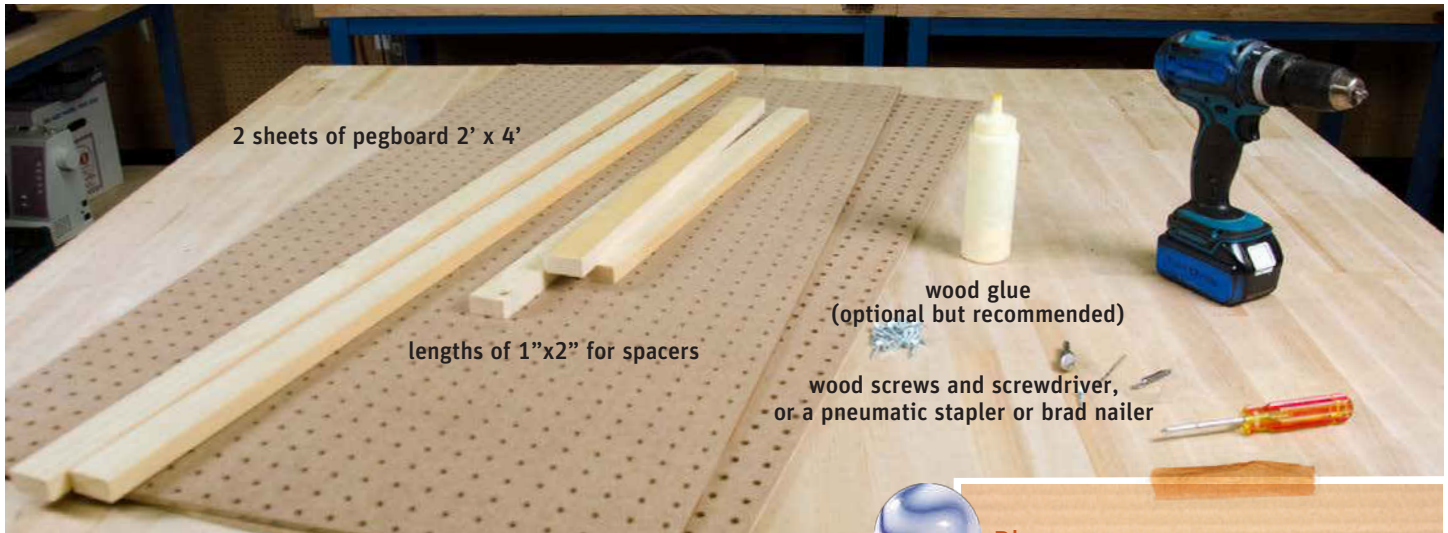


### Parts and Tools for Construction:

This will show you everything you need to know about making a marble board for this activity. Don't be intimidated by the building process. It is straightforward and can be done even if you are new to woodworking.

We recommend this project be done by ages 14 and up, with supervision. Younger kids can also be included with proper guidance.

Our guide shows how to build a personal marble machine board for one or two people to work together on. In different environments we have expanded these small-scale building spaces into larger collaborative environments. With some creativity you can modify these instructions to fill a room with pegboard walls or build a freestanding fort with interesting angles and overhangs.



Plus:  
dowel pegs (for alignment) and  
a friend (recommended)

**Step 1:** This project requires some materials, easily obtainable from your local hardware store.

You will need:

- 2 sheets of pegboard - 2 feet x 4 feet
- 2 lengths of wood - 1 in x 2 in x 4 feet (vertical spacers)
- 3 lengths of wood - 1 in x 2 in x 22.5 in (horizontal spacers)
- wood glue (optional but recommended)
- wood screws
- power drill
- drill bit and driver bit
- countersink bit (optional)
- 1/4 in dowels (you will use these pegs for alignment)
- a friend (recommended)

**Step 2:** Align pegboard and vertical spacers

Set one of the pegboard panels on top of the two long vertical spacers. Do this with both spacers at once to keep the panel level. Make sure edges and sides of the spacers are flush with the panel. Just running your fingers along the edge will do the trick.

Tip: Long pieces of wood are often slightly curved. This is not a problem, as they can be straightened when fastening them to the pegboard, but make sure they are flush on one end to start, and straighten them as you work your way along.



### Step 3: Pre-drill pegboard and vertical spacer

Once your spacers are aligned and flush, you'll pre-drill all your screw holes to avoid splitting the wood with screws. Start at one end, and drill a small hole where the first screw will go.



*Tip: If you want your board to look extra slick and have all the screws be flush, you can use a countersink bit to make room for the screw heads. Now is the time to do so.*



Put the first screw in to tack one end in place while you pre-drill the rest. If you plan on using glue, don't put the rest of the screws in yet. If you're skipping the glue, feel free to add screws as you go along.

Pre-drill every 6 inches or so down the length of the board. If you notice the spacer is warped or bent, pull or push it flush with the edge of the board as you go. This will help keep things aligned when you permanently attach the board to the spacers.



### Step 4: Attach spacers

If you've decided to use wood glue, lift the board off the spacers, and apply glue all the way down the one you pre-drilled. Use a wavy pattern for better coverage and style. If you've decided not to use glue, you can leave the board in place.

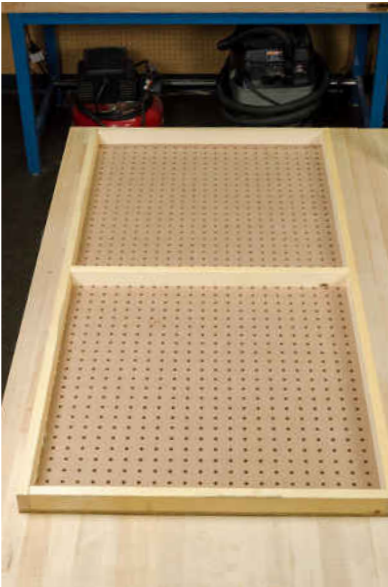


Put the board on top of the spacers again, and drive screws in the holes you pre-drilled. The screws should find the pre-drilled holes and line everything up nicely!

It's normal for some glue to squeeze out; use a damp cloth to wipe it up (your finger will also work in a pinch).

Repeat the whole process with the other vertical spacer.



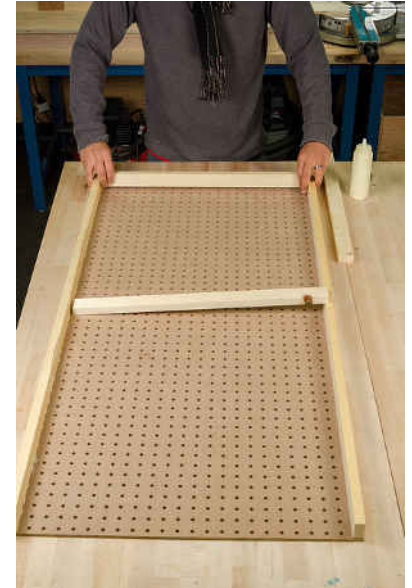


**Step 5: Place the horizontal spacers**

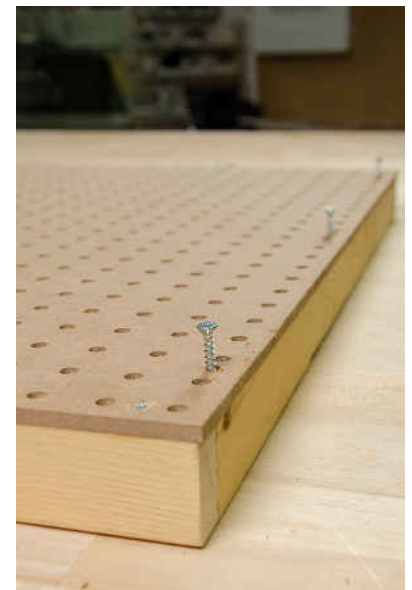
Next, you will add horizontal spacers to your board. These provide structural integrity and prevent the pegboard panels from bowing inward.

Flip your board and put a horizontal spacer on each end and one in the middle. Take care to place the middle spacer so it doesn't block any of the holes.

If the fit is tight, the spacers will stay in place. If not, use masking tape to keep them in place.



Flip the board over again and pre-drill, countersink (optional), and screw the horizontal spacers in place.

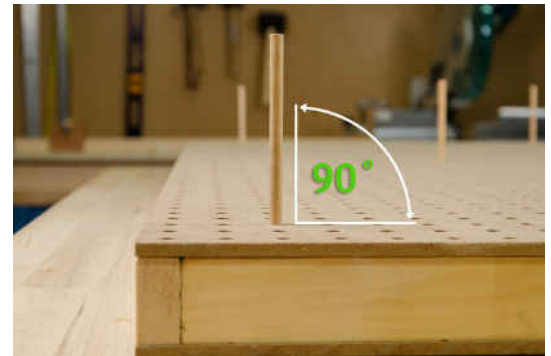




**Step 6:** Add the second pegboard panel  
Flip your board over again.  
Place the second pegboard panel on top.



Use at least three dowels to align the holes in the top panel with the one on the bottom. It is important to make sure the dowels will stick straight out when you're building your marble run.



Stick dowels through both sets of holes, and visually check that they are vertical. Often, fixing a dowel in one spot will make others lean; keep adjusting until they are all as close to vertical as you can get. It doesn't have to be perfect, close is good enough.



Now you're ready to pre-drill and countersink (optional) the whole panel. Don't forget to pre-drill the horizontal spacers too, including the one in the middle, which is now hidden.

If you're not using glue, you can screw the panel in now. If using glue, lift it off, apply glue, and replace it before screwing it in.

Tip: Sometimes it's helpful to use dowels again to confirm the panels are aligned before screwing it together.







**Step 7:** Your board is nearly done.

Take a moment to be proud of your board. The hardest part is done. When you're ready, move on to the next step: make feet so your board can stand on its own.

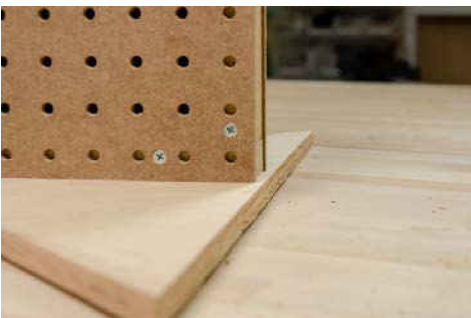
**Step 8:** On your feet!

Find or cut a piece of plywood that measures about 15 inches square. Draw a line from corner to corner and cut the square into two equal triangles (feet).



Locate the center of the long side of each triangle and mark it. If you draw a line with a ruler from this mark to the point on the other side you'll have a nice centerline. Decide which side of your marble board you want to have as the bottom. Use the centerline on one of your feet with to center it on the edge of your board.

Tip: This is a great time to have a friend helping because it's tricky to keep the board steady when it's standing on end and you are trying to drive screws into it.



Instead of making the foot flush with the bottom, make it stand out, or "proud," by 1/4 inch. This will make your board much more steady, particularly if the floor isn't perfectly flat.

You should pre-drill, and countersink (optional), and screw in one of the feet. Then flip the board and repeat with the other side.

A quicker and easier way to make feet is to use a straight piece of wood about 18 or 20 inches long, and screw that in place. It won't be as durable as the triangle feet but it will work. Remember to keep it "proud" of the bottom by 1/4 inch.

## Step 9: Hooray! A Completed Marble Board Masterpiece



This is just one way to build a marble board. We find it works well for us. There are plenty of other ways that will also work: the size of the pegboard and spacers can change, the feet can change, the edge can be routed, or finished with end caps, or left rough. The important thing is gaining an understanding of why it's built this way, then you can transfer your knowledge into other designs.

First things first though: start making some marble runs! As you do you'll start to understand the wonders and the character of your board and you can make changes to suit your needs. Now that you know how to build a Marble Board, make sure to teach someone else!

