Material Property Game

Facilitator's Guide

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This guide includes all the information needed to facilitate students playing the "Material Properties Game" in the classroom.

Materials are all around us and certain materials are chosen for specific applications based on their properties, or how they react/behave under specific conditions or stimuli. One way material properties are compared with one another is with a property chart (*i.e.* Ashby Chart). These charts are very helpful when performing materials selection, or choosing materials for an application.

This game allows students to explore properties of different materials and build their own Ashby charts, thus gaining familiarity with materials and why they might be used in different applications in the process.

Learning Objectives:

After playing this game, students will be able to:

- Estimate material properties based on simple experiments
- Analyze and visualize material property data using a material selection (Ashby) chart
- Comprehend trends and differences between material families
- Understand the concept of materials selection and its importance during the engineering design process*

*This is considered a more advanced learning objective and requires additional information/context beyond playing the game. Check the expansion portion of this guide for more details.

Age Range:

This resource has been designed for flexibility in terms of (1) content level, (2) budget[1], and (3) time.

Therefore, depending on the facilitator's choices (illustrated throughout this document), this game can be played by students from **age 5+** all the way to **college**.

1 Specific costs are not listed due to high degree of variability in different countries. However, the simplified tests and hand-drawn board would generally be considered the cheaper option.

Zip File Contents:

Multiple files are included in this game download. A comprehensive list can be found here. Details on where to use specific files will be included throughout the guide.

1- Read this to get started [folder]
- 1- Overview of the Material Properties Game.pdf
- 2- Facilitators Guide.pdf

2- Preparing the game [folder]
- 1- Manufacturing and Assembly Files [folder] (see Appendix A for use instructions)
  - > 1- Physical Board [folder]
    - » 5x1 Slider.dxf
    - » 5x5 Game Board Drawing.pdf
    - » 5x5 Game Board.dxf
    - » 12x1 Slider.dxf
    - » 12x12 Game Board.dxf
    - » Chart Labels.html
  - > 2- Hand-written Board [folder]
    - » Hand-written board template.pdf
    - » Hand-written ranking bars template.pdf
  - > 3- Capacitance and Electrical Resistance [folder]
    - » Ball Holder.stl
  - > 4- Newton_s Cradle [folder]
    - » Backgrop.dxf
    - » Ball sling (two needed for Newton_s Cradle).stl
    - » Bottom.dxf
    - » Newton_s Cradle Drawing.pdf
    - » Support.dxf
    - » Top.dxf
    - » Window.dxf
- 2- Print for class [folder]
  - > Measurement table.pdf
  - > Score cards.pdf
  - > Solution posters.pdf
- 3- Print for stations [folder]
  - > Measurement Cards [folder]
    - » Instrument_Measurement Instruction Cards.pdf
    - » Touch and Feel_Measurement Instruction Cards.pdf
  - > Property Cards [folder]
    - » Advanced_Property Cards.pdf
    - » Touch and Feel_Property Cards.pdf

3- Present to class [folder]
- Material Property Game Instructions & Discussion.pptx

Game Basics:

This game consists of three major phases:

1. Material Property Estimates based on Measurements
   - Students move between stations to measure various material properties using physical samples
2. Material Property/Ashby Chart Creation
   - Once all property measurements are ranked, students come back together and assemble property charts
   - Charts are compared with solutions to check for accuracy
3. Discussion/Expansion
   - Class discussion around (1) lab measurements and accuracy, (2) material properties, (3) different material families, and (4) materials selection *[optional]*

Detailed instructions can be found later in this document.

Game Play Options

As stated above, this game has a lot of flexibility in how it is run.

The *Introductory* column choices were designed for younger audiences, lower budgets, or constrained class time. The *Advanced* column choices were designed for older audiences, higher budgets, or more flexible class time.

The property and measurement cards must match in level (*i.e.* there are no simplified property cards for the majority of properties measured using instruments) but either game board option works, regardless of measurement techniques.

Options	Simplified	Advanced[1]
Property Cards *Definitions of the various properties being measured*	Simplified	Detailed/Complex
Measurement Cards *Instructions for measuring each property*	"Touch & Feel" measurements	Instrument measurements
Game Board *Used to create the property charts*	Hand-drawn	Physical[2]

1 This version was originally designed for use in introductory college courses at the University of Victoria and CalPoly SLO by the authors at institutions 1 and 3 on the cover.
2 Note: Files for creating the board are .DXF. Recommended only if using spherical material samples

Now that you have chosen your different game play options, use the linked table below to navigate this document. Details on Equipment Needs, Pre-Activity Preparations, Day-of Set Up, and more for each option above are included, as well as optional extension activities, additional resources, and tips & tricks!

Table of Contents

Game Equipment Needs

This game needs some equipment to perform the material measurements and create the chart game boards. Details on what to purchase, potential sources, and more are included below.

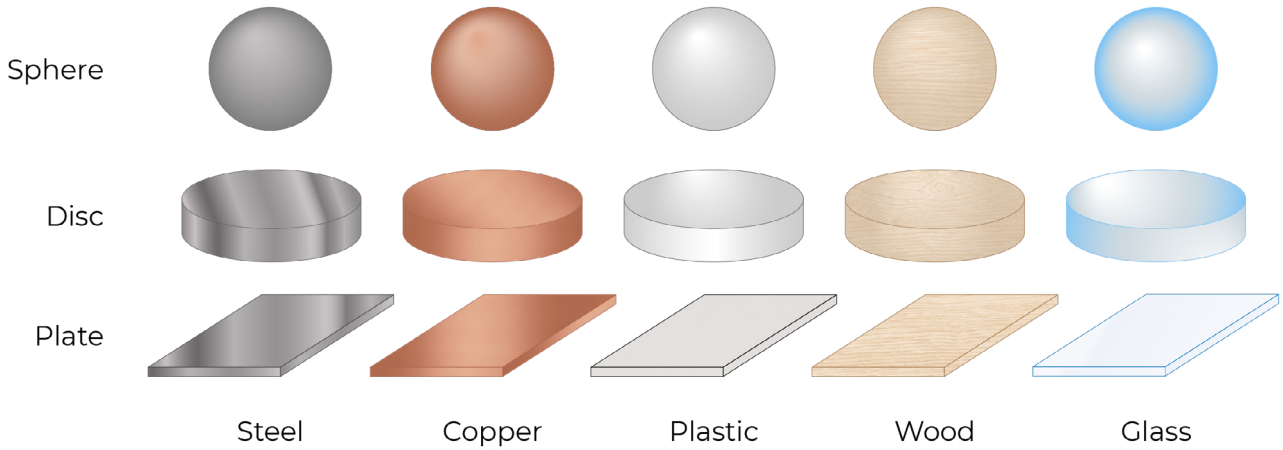
Material Samples

These activities require physical material samples to perform the various measurements on.

The exact number of samples needed depends on the number of students, number of measurement stations, and general organization of activity (check Game Details and Alternative Game Play to get more details on how students utilize the samples during the game).

> TIP We recommend a minimum of five different material samples for this activity. Based on our research, the easiest materials to source are: Glass, Wood, Metal, and Plastic. Check out the Solution Posters document for more details!

The shape is also not strictly enforced (unless utilizing the physical game board- in which case spherical is recommended), but **all samples** must be the **same shape and size** to ensure consistency across measurements. Some example shapes are shown below.



> TIP When purchasing material, plates and discs could be made from bulk sheets/ rods, if one has access to the means to cut said material.

Where to Source Materials

Industrial supply companies or hardware stores are two potential sources for these materials.

Example: Grainger Industrial Supplies

Measurement Instruments and Supplies

The equipment needs for the measurements are broken into the two categories: Introductory and Advanced. Details on how to perform these experiments can be found on the measurement cards and Appendix C of this document.

Introductory Measurement Equipment

These tests were designed to need little to no equipment. The measured values are estimates only.

Test	Necessary Equipment	Optional Equipment
Tactile Warmth	None	N/A
Touch	None	N/A
Pitch	Spoon/ other solid object to tap samples with	N/A
Density	None	Kitchen scale/balance

Advanced Measurement Equipment

These tests require more instrumentation than the Introductory level measurements, however you may already own some of this equipment in your classroom/lab.

Test	Necessary Equipment	Optional Equipment
Density	Scale/balance	Spherical sample holders
Thermal Conductivity	Infrared thermometer Heating element/hot plate	Could use ice if heating element is not an option
Electrical Resistivity	Multimeter with leads	Spherical sample holders
Mechanical Loss Coefficient	- Newton's Cradle[1] - Camera with slow-motion capabilities - Spherical sample holders + 2 samples of each material	Tripod to ensure steady filming
Dielectric Constant	Capacitance meter with leads	Spherical sample holders
Mohs Hardness[2]	Mohs Hardness pen set	N/A

1 *Requires additional manufacturing. Details in Appendix A. This test is considered highly variable in results.*

2 This is an additional test option, recommended by University of Victoria authors. No additional documentation on this test is included in this guide at this time.

Where to Source Equipment

Much of this equipment can be sourced from science lab vendors, such as Thermofisher. In the case of the Newton's Cradle, this must be constructed. Materials for this can be found at most hardware stores.

Game Board

Two board games can be created for this game. Details of materials needed can be found below.

Board Style	Materials Needed to *Create* Board	Materials Needed to *Use* Board
Hand-drawn	- Transparent film/sheet protector - Board template printed[1] - Black permanent marker	Non-permanent markers in multiple colors
Physical	- Material compatible with laser cutter[2]	Spherical samples[3]

1 Details on how to manufacture can be found in Appendix A
2 A clear material, such as acrylic, is recommended to be able to slide solution poster underneath. Authors used 3/8" think material. Details on how to manufacture can be found in Appendix A
3 Disc samples could be used, provided the diameter is the same as the holes in the physical game board

Where to Source Materials

For the hand-drawn board, materials can be found from an office supply store or online vendor.

For the physical board, materials can be found at a hardware store or online.

Pre-Game Preparations

Once Game Play Options are chosen and equipment and materials are procured, some pre-game preparations need to be completed.

Some preparations create consumable items for the game, while others only need to be printed or made once. Items that can be reused will be marked with a star*.

All files for the pre-game preparations can be found in the *2-Preparaing the Game* Folder.

What to Print

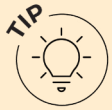
There are two general categories of items to print, shown by the subfolders: Print for Class and Print for Stations. The breakdown from the file structure, along with which are resuable, is shown here.

2- Print for Class Subfolder

- Measurement table
- Score cards
- Solution posters*

3- Print for Stations Subfolder

- Measurement Instruction Cards
  - » Instrument_Measurement Instruction Cards*
  - » Touch and Feel_Measurement Instruction Cards*
- Property Cards
  - » Advanced_Property Cards*
  - » Touch and Feel_Property Cards*



» To avoid having to reprint reusable items, we suggest laminating them!
» Using the measurement table template and score cards are optional.

What to Make

Detailed instructions on how to make these items can be found in Appendix A of this document. All files needed are in the *1-Manufacturing and Assembly Files* subfolder.

1. Hand-drawn board* (if using)
2. Physical game board* (if using)
3. Spherical sample holders*(if using)
4. Newton's Cradle setup* (if using)

Creating the hand-drawn boards could be an in-class activity, depending on the age of students and time available

Game Setup

Everything has been prepared- now it is time to setup to play the game!

Stations need to be setup for the first two phases of the game: (1) Property Measurement and (2) Chart Creation. Both are illustrated below.

Property Measurement Stations

You will need minimum one station per property being measured. Use the numbers from the Equipment Needed List to see an example of the setup in the image below.

Equipment Needed:

1. Material samples
2. Property definition card
3. Measurement instruction card
4. Property measurement equipment (if required for particular property of choice)

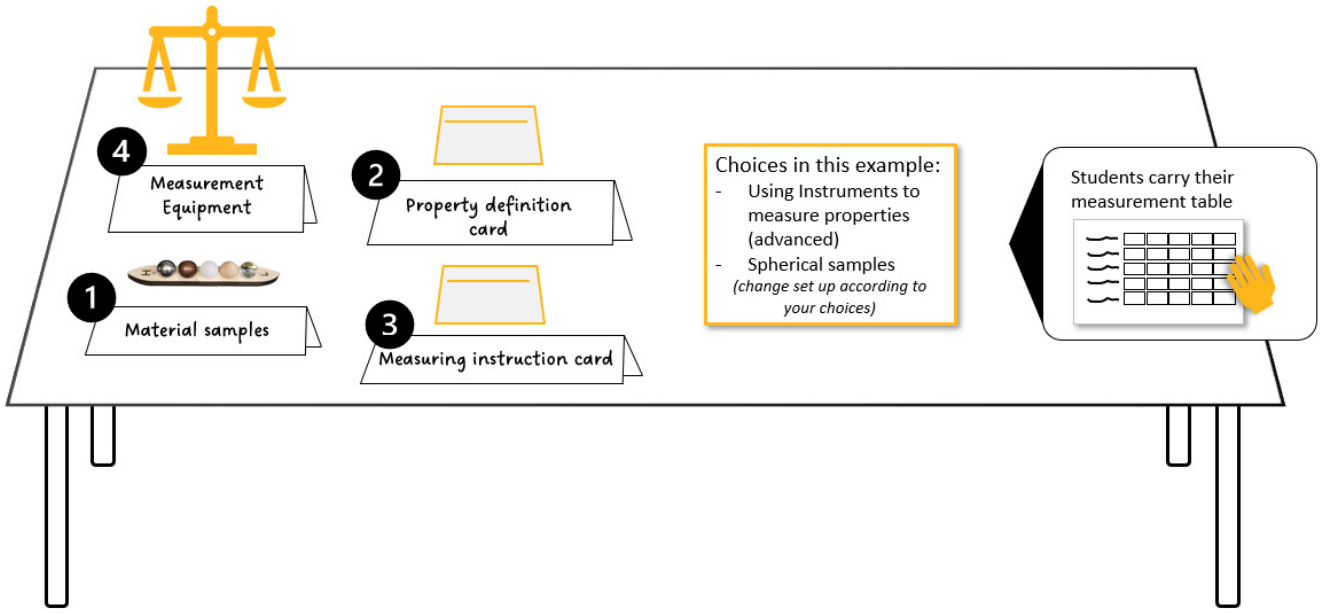
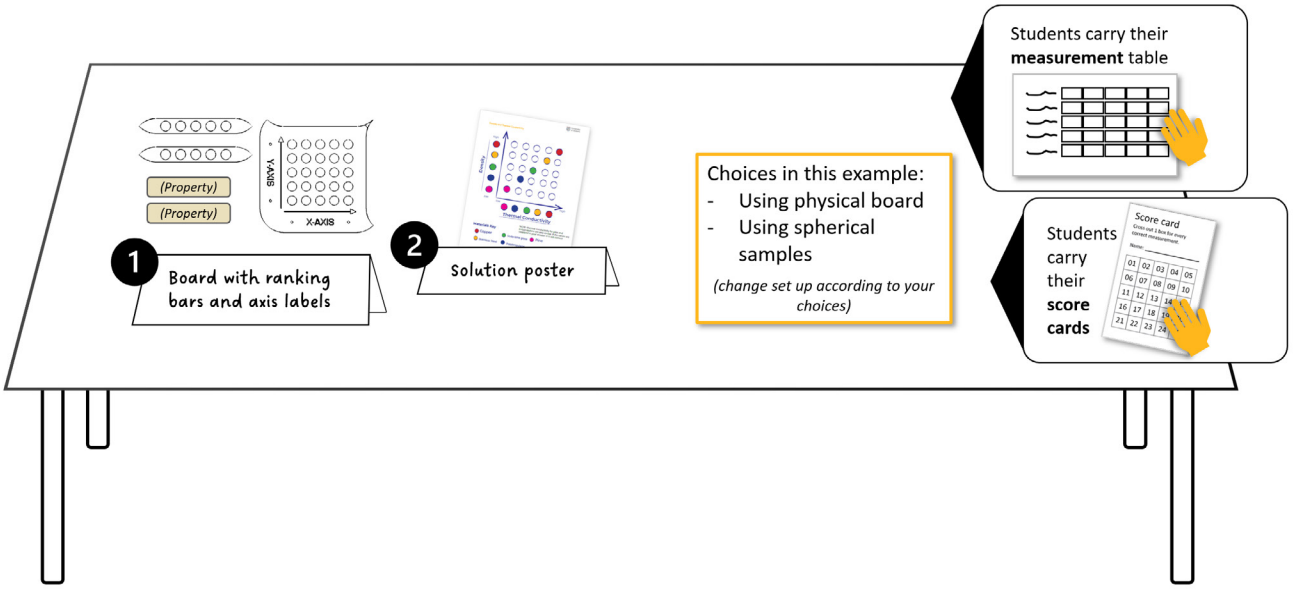


Chart Creation Stations

Below is an example of a Chart Creation Station, as well as the equipment needed list. If students are working in groups, each group could have one Chart Creation Station. If students are working individually, they may have to take turns (depending on number of boards, *etc.*)

Equipment Needed:

1. Board with ranking bars and axis labels
2. Solution posters



TIP If you want to increase suspense, you can hide the solution posters in a folder and have all groups reveal the answers at once

Game Play Details

Instructions for students to play the game are included as a PowerPoint presentation to be shared with the class (file: Material Property Game Instructions & Discussion.pptx)

Facilitator instructions are found below, which are broken into phases based on the categories stated earlier in the document. *Note*: Phase 3 is not listed here due to that being solely focused on in-class discussion/teaching and does not involve "playing" the game.

Game Phase 1: Property Measurement

Step 1: Measure Material Properties

1a. Moving between the measurement stations, students measure the properties for each material sample[1] utilizing the instruction cards and equipment provided.
1b. Property values are written down, either on the Measurement Table or in a notebook.

Step 2: Rank Materials

2a. Once all sample values are collected for a single property and noted in the Measurement Table or a notebook, materials are **ranked** from *Lowest* to *Highest*
- This information is critical for the Chart Creation Phase!

Game Phase 2: Chart Creation

Use Step 3 instructions that align with board choice

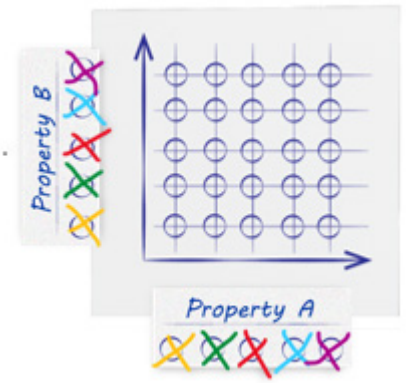
Step 3: Create Property Chart(s) [hand-drawn board]

3a. Mark material on ranking bar according to **Step 2 ranking values**
- Use unique color markers for each material[2]

3b. Assemble board with ranking bars and axis labels
3c. Transfer markings from ranking bars to the board
- Mark the spot where both property measurements for a material meet with the same color marker

Step 3a

Step 3b



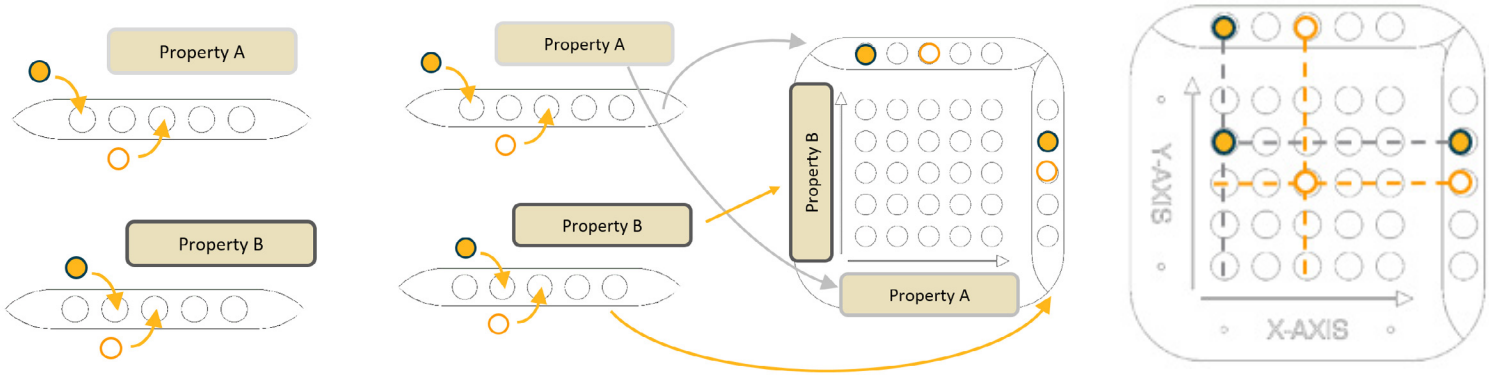
Step 3c

1 Check Appendix B: Alternative Game Play to see different options for this step
2 Using non-permanent markers will allow ranking bars and game boards to be re-used

Step 3: Create Property Chart(s) [physical board][3]

3a. Place marbles on ranking bars according to **Step 2 ranking values**
3b. Assemble board with ranking bars and axis labels
3c. Transfer material from ranking bars to board
- Place the same type of marble on the spot where both property measurements for that marble meet

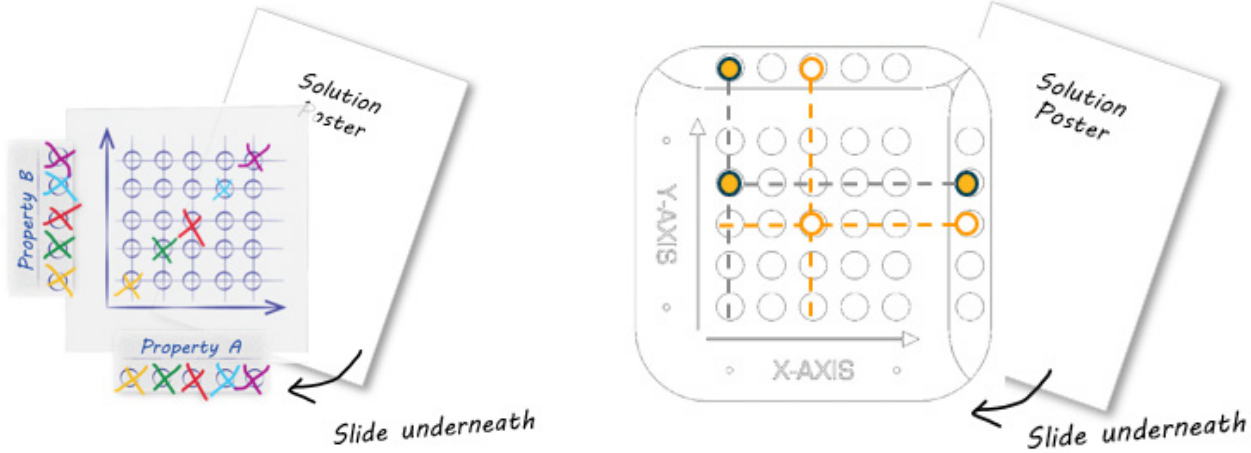
Step 3a ***Step 3b*** ***Step 3c***



Step 4: Check Chart Accuracy

Slide the Solution Poster underneath the board to check material mark/marble placement

Step 5: Score [optional]



Using the Score Card, mark how many spaces on the board matched the solution poster

Two ways to use the Score Card:
1. One card per board- mark each correct space (empty or filled)
2. One card per 5 boards- mark if correct space for material placement only

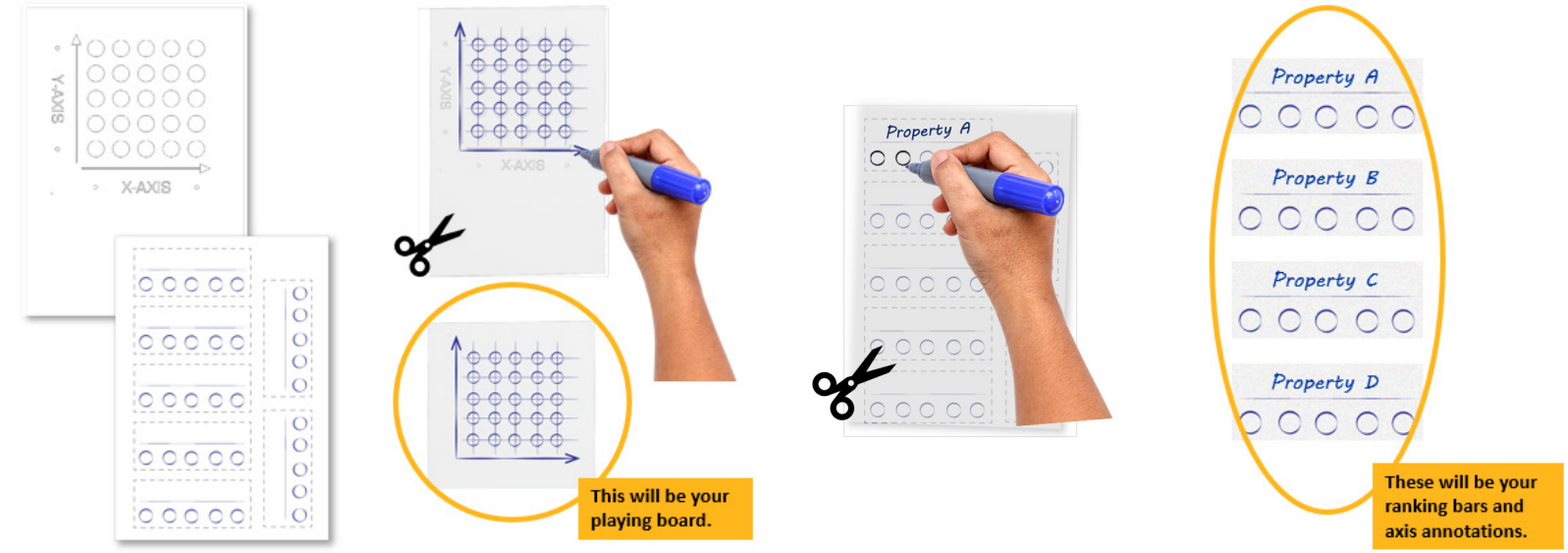
3 This setup requires 3 sets of spherical samples

Appendix A: Detailed "What to Make" Instructions

Hand-Drawn Board

1. Print templates for board and ranking bars (*Folder 2- Preparing the Game → 1- Manufacturing and Assembly Files → 1-Hand-Written Board)*
2. Put transparent film/sheet protector on top of the board template and trace with a **permanent** marker
    - This is the game board!
3. Put transparent film/sheet protector on top of the ranking bar template and trace with a **permanent** marker and **cut** along dotted lines
4. Label each strip with a material property using a **permanent** marker
    - These are the ranking bars and axis labels in one.

Step 1 ***Step 2*** ***Step 3*** ***Step 4***



Physical Game Board

The game board was created by the University of Victoria authors by laser cutting 3/8" thick acrylic. The .DXF files for creating the physical game board in multiple sizes (5x5 and 12x12) and the labels can be found in the folder:

Folder 2- Preparing the Game → 1- Manufacturing and Assembly Files → 1-Physical Board

Spherical Sample Holders

The spherical sample holders were created by the University of Victoria authors via 3D printing. The .STL file needed to create this holder can be found in the folder:

Folder 2- Preparing the Game → 1- Manufacturing and Assembly Files → 3-Capacitance and Electrical Resistance

Newton's Cradle

The Newton's Cradle aparatus was created by the Unviersity of Victoria authors via laser cutting balsa wood and 3D printing sample holders. The .DXF and .STL files needed can be found in the folder:

Folder 2- Preparing the Game → 1- Manufacturing and Assembly Files → 4-Newton_s Cradle

Appendix B: Alternative Game Play

There is no right or wrong way to play this game- the instructions earlier in this document are an example of one way the creators of this game have run the activity in their courses. Below are some other options we have brainstormed during the creation of this document.

Note: many of these ideas have not been tested in a classroom. User discretion advised!

Building a Property Chart as a Class

The instructions showcase students working alone or in groups to measure each material for every property. However, time can quickly add up working in this way; with minimum *five* materials and minimum *four* tests recommended, each student/group is taking at least *20* measurements!

One alternative is to have each student/group be responsible for one single material. Now, instead of each student/group taking 20 measurements, they are taking four.

> TIP If time/participant numbers allow, consider increasing the number of material samples being explored. How big of a property chart could you make?

Once all the data is gathered, the class comes back together to build one or two big property charts.

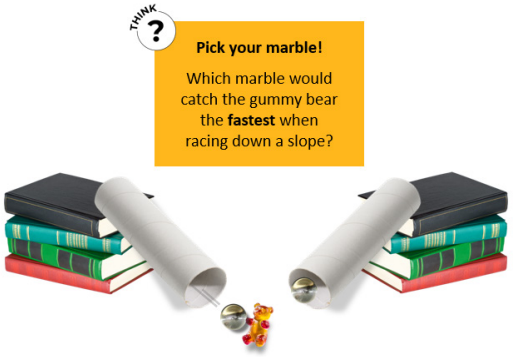
> TIP Build the chart on the board at the front of class, then project the solution poster on top to check the answers!

Racing for the Gummy Bear

While we think materials are pretty neat, we understand that this game might need some incentive beyond learning about this awesome topic.

We have included the score cards as one way to provide some low-stakes incentive.

Another option is what we are calling "Racing for the Gummy Bear".



Equipment Needed:

- Spherical material samples
- Empty paper towel/toilet roll tubes
- Gummy bears

After discussing more about the material properties students measured during the game, you can pose the question "Which material would catch the gummy bear the fastest when racing down a slope?"

This can be connected to material density, friction, and other properties. Have this as a tie breaker activity for score cards or just a fun way to apply their material property knowledge!

Appendix C: Property Measurement Instructions

As stated above, these instructions are available for students on the Property Measurement Cards. But, to allow easier understanding for facilitators, we have included the information here.

Touch & Feel Measurements

Tactile Warmth

Touch each material separately. Rank materials from warmest to coldest.

Touch

Hold each material sample separately. Rank materials from soft to hard.

Pitch

Tap each sample lightly with a spoon. Rank the materials from low to high pitch.

Density

Hold each sample. Rank the materials from lightest to heaviest.

Advanced Measurements

Density

Step 1: Prepare Scale

- Turn on scale and hit tare/zero to ensure a zero measurement before placing any material samples.
    - *if using a sample holder, make sure to zero balance of holder to ensure it does not impact sample measurement

Step 2: Measure sample

- Place sample on scale, wait for value to equilibrate, and record the mass.
- Remove sample, then place on scale a second time and record the mass a second time.
- Take the average the two measurements to get the final value for the mass.

Step 3: Calculate density

- Using the equation above, calculate the density of the sample.

Record the Density value in your Measurement Table for material ranking and chart step.

Thermal Conductivity

Step 1: Initial Temperature Measurement

- Turn on the heating element and give a few minutes to reach the desired temperature (to be determined by your instructor- do not exceed 50°C!!).
- Place material sample on the heating element.
- Record initial temperature value (T_1) of sample.

Step 2: Equilibrated Temperature Measurement

- Allow sample to rest on heating element for an additional three minutes.
- Record second temperature value (T_2) of sample.

Step 3: Calculate Heat Transfer Rate

- Subtract T_2-T_1.
- Record heat transfer approximation under "Thermal Conductivity" in your Measurement Table for material ranking and chart step.

Electrical Resistivity

Step 1: Experimental Electrical Resistance Measurement

- Select the Resistivity/Ω setting on the multimeter, then press measurement probes firmly on either side of the sample
- Record measured value for Step 2 calculation.

Step 2: Intrinsic Material Property Electrical Resistivity Calculation

- Using the measured resistance from Step 1, calculate the electrical resistivity using the below equation.

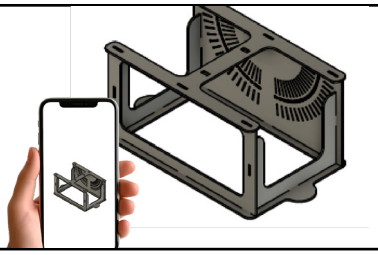
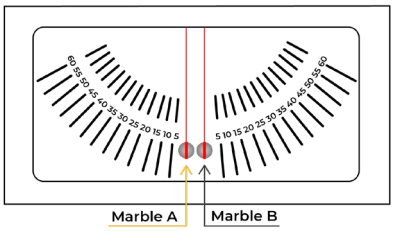
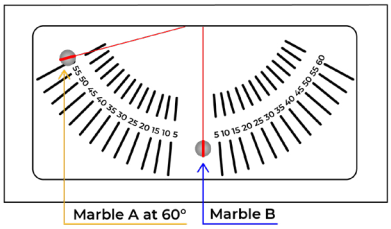
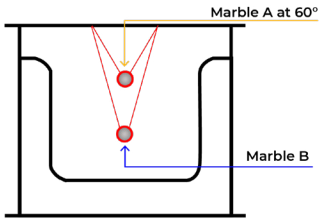
$$\rho_e = \frac{RA}{l}$$

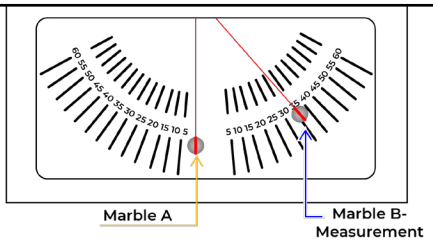
where: R= electrical resistance, A= sample cross sectional area perpendicular to direction of current, ρ_e= electrical resistivity, l= length of test sample

- Record Electrical Resistivity in your Measurement Table for material ranking and chart step.

Mechanical Loss Coefficient

NOTE 1: this experiment requires spherical samples
NOTE 2: for this experiment, we are measuring the degree difference after two marbles of the same material collide. While this is not exactly the same as measuring the mechanical loss coefficient, the measured results should scale well with the material's real loss coefficient value, meaning our ranking results are still correct.

Step #	Sub-step	Actions	Clarifying Image
1 Experiment Setup	a	Set up the Newton's Cradle and phone camera opposite the Cradle (camera should capture the entire cradle)	
	b	Place two marbles of the same material in the ring holders	
2 Run Experiment	a	Raise Marble A so the supporting string is aligned with the **60-degree line** (make sure it is in camera view!)	
	b	Double check marble alignment from side view (marbles should be on the same path)	
	c	Begin slow-mo video recording	N/A
	d	Release Marble A	N/A
	e	Stop recording once marbles have completed 2-3 swings	N/A

Step #	Sub-step	Actions	Clarifying Image
3 Gathering information via video	a	Scroll through video recording to find the highest point Marble B reached after collision	
	b	Record the degree line value *If the string is between two lines, make an estimate (*ex:* between 50 and 55 degrees is approximately 52.5)	N/A
4 Determine degree difference	a	Subtract 60°-measured degree value to get the degree difference	N/A
	b	Use this value to rank the materials. A low number of degrees lost corresponds with a low mechanical loss coefficient (less energy lost upon collision)	N/A

Dielectric Constant/Relative Permittivity

NOTE: for this experiment, we are measuring "capacitance" of our material. Because this measurement is done outside of a capacitor (see Property Definition Card for more details), the measured property is technically not the dielectric constant. However, the measured results should scale well with the material's real dielectric constant value, meaning our ranking results are still correct.

Step 1: Setup for experiment

- Check the capacitance meter scale (start with pF and increase if needed).
- Connect multimeter leads to color-coded positions on the back

Step 2: Take capacitance measurement

- Press leads to the two opposite sides if the sample for the most accurate measurement (utilizing sample holder for spherical samples)
- Wait until number stabilizes (adjusting scale as needed)
- Use this number to rank materials

Appendix D: Additional Ansys Resources

If you have made it this far in the document, well done and many thanks for looking into our resource!

We have a number of other resources that could benefit both student and instructor, especially if materials-related topics are new to your classroom.

Check out the resources linked below, many of which were designed specifically with pre-university classrooms in mind.

1. Materials Intelligence: the Card Game
2. Why this shape? Exploring the historical and structural significance of the Arch part 1
3. Selecting Materials for Musical Instruments: a Case Example with a Xylophone
4. Life's Engineering Tales, featuring: An element's journey
5. Life's Engineering Tales: Grandma's Hip Replacement
6. Our Impact on the planet: let's make it a good one!
7. The Materials Cube
8. Exploring the Evolution of Materials via Property Charts
9. Material Property Chart Collection

If you are an instructor, or your students want to learn more about materials science and selection materials in design, we recommend checking out our free Ansys Innovation Courses on the topic. A few related to this game are linked below.

1. Materials Selection with Ashby Charts
2. Intro to Material Performance

If you have access to Ansys Granta EduPack™, a teaching software for materials education[4], there are some additional areas for expansion.

1. Try recreating the property charts created in the lab- do you notice trends across entire material families?
2. Explore the aesthetic attributes in the Design Database- what similarities do you see to engineering properties?
3. Follow along with the Basics of Materials Selection Ansys Innovation Course- what value do property charts add to this process?

4 Don't have access but are interested in learning more? Check out our product webpage here or email us at education@ansys.com!

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Document Information

This game is part of a set of teaching resources to help introduce students to concepts in science, technology, engineering, and math.

Ansys Education Resources

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