

Pick the Spoon: Property Data Decides

Investigation question: A kit for melting candle wax and chocolate needs a stirring spoon. Seven materials are available. Which one should the company choose, and how do you decide fairly when no material is perfect?

Data-driven decision

Groups of 4

1 session

Setup 6 · Activity 40 · Cleanup 6 min

MS-PS1-2 · practice

MS-ETS1-2 · practice

MS-ETS1-3 · practice

Scientific purpose

Students use a table of property data (density, melting or softening temperature, water behavior, flammability, heat conduction and cost) to choose a material for a stirring spoon that sits in hot wax. They apply a systematic process: screen every candidate against must-pass criteria first, then score the survivors on the remaining criteria, and finally test their recommendation against the trade-off it still carries. A verification station lets them measure density for real samples and watch what hot water does to wax and polypropylene, so the table is not taken on faith.

Why this helps students with this chapter

Students tend to pick the material with the single most impressive number, such as the highest melting point, and ignore everything else. The spoon problem is built so that every candidate fails something: wood soaks up water, wax and PLA soften in the pot, steel is heavy, metals burn your hand, plastics can catch fire. The screen-then-score process gives students a fair way through, and the verification station connects the numbers in the table to objects they can hold.

Standards connections

MS-PS1-2 (practice, interpreting density, melting point, solubility and flammability data to compare substances): Students read and compute with the properties the PE names in its assessment boundary and use them to compare materials, which is the data-interpretation practice the PE requires; no reaction is observed, so the role is practice.

MS-ETS1-2 (practice, evaluating competing candidates with a systematic screen-then-score process): The criteria and constraints are supplied, and students apply a systematic process (must-pass screen, weighted scoring) to seven competing options, which is the heart of the PE. It is practice rather than assesses because students do not define the problem and the candidate set is small and given.

MS-ETS1-3 (practice, combining the best characteristics of two candidates): The final design question invites students to combine a metal bowl with a plastic handle, using property data from each, which is the combine-the-best-features idea of the PE in a simple form.

Roles (rotate each session)

- **Data lead:** Reads each property from the table aloud, computes spoon mass and cost for each candidate, and checks the arithmetic of the others.

- **Screener:** Applies the three must-pass criteria to each candidate, records pass or fail with the property that caused the fail, and keeps the list of survivors.
- **Scorer:** Scores the survivors on the four scored criteria using the group's agreed scale and totals the matrix.
- **Station tester:** Runs the verification station: measures mass and volume for the four samples, records what the hot-water test does, and reports back whether the table values held up.

Materials

Item	Quantity	Per	Note
Property data table and recording sheet	1	student	
Calculator	1	group	
Steel bolts or nuts, about 50 g total	1 handful	group	Zinc-plated is fine; the plating is too thin to change the density.
Polypropylene bottle caps (marked PP or recycling code 5)	6 to 8	group	Enough to raise the water level by about 10 mL when pushed under.
Pine block, about 2 cm × 4 cm × 8 cm	1	group	Any softwood offcut; sand the edges square so a ruler measurement works.
Chunk of plain paraffin candle wax, about 10 g	1	group	Cut from an unscented white candle; remove the wick.
Graduated cylinder, 100 mL	1	group	
Digital balance reading to 0.1 g	1	group	
Ruler marked in millimeters	1	group	
Bent paper clip or stiff wire to push floating samples under water	1	group	
Paper towels	3 sheets	group	
Electric kettle and a heat-safe clear container for the hot-water station	1	class	Teacher-operated; water at about 80 °C.
Tongs and a thermometer for the hot-water station	1 set	class	

Estimated cost: 6 to 10 per class (an estimate; A bag of steel bolts about \$3, one unscented candle about \$1, a pine offcut from a hardware store scrap bin about \$1 or free, bottle caps collected for free; kettle, cylinders, balances and rulers are school stock.)

Safety

- The hot-water station is teacher-operated only. Water at 80 °C scalds instantly; students observe from arm's length and never pour, reach into or move the container. Use tongs for every sample.

- Keep the hot-water container on a tray away from the bench edge and away from cords and backpacks.
- Steel bolts dropped into a glass cylinder can crack it; lower them in with the cylinder tilted, or use a plastic cylinder.
- Pine dust and wax shavings can irritate eyes; brush samples off the bench into the waste, not onto the floor.
- No flames anywhere. The flammability column in the table comes from reference information, not from a demonstration.
- Wipe up water spills at once; wet floors near a balance table are a slip hazard.

Teacher preparation and setup

1. Collect polypropylene caps (code 5) for a week ahead; soda and water bottle caps are usually PP. Avoid caps with foam liners, which trap air.
2. Cut the pine blocks and the wax chunks; weigh one set yourself and compute the densities so you know what the station should give (steel about 7.8, PP about 0.90, pine about 0.4 to 0.55, wax about 0.90 g/cm³).
3. Print the property table on the recording sheet and post a large copy. Decide the scoring scale you will require (the sheet suggests 3 = best, 2 = middle, 1 = worst for each scored criterion).
4. Set up the hot-water station at the teacher's bench: kettle, a clear heat-safe container, thermometer, tongs, and a tray. Plan to run it for two groups at a time, at about 80 °C, with you doing all the pouring.
5. Work through the screen yourself so you can check groups quickly: wax, PLA and pine fail the must-pass screen; aluminum, stainless steel, polypropylene and nylon survive.

Investigation design

Independent variable	The candidate material (seven options in the data table; four real samples at the station).
Dependent variable	Whether each material passes the screen, its score on the remaining criteria, and at the station its measured density and its behavior in 80 °C water.
Controlled	Same spoon volume (30 cm ³) for every candidate when computing mass and cost; Same must-pass thresholds and the same 3-2-1 scoring scale for every material; Station: same cylinder, same balance, samples dried before weighing; Hot-water test: same water temperature (about 80 °C) and the same two minutes for each sample
Trials	One screening and scoring pass per group, compared across groups in the debrief; station density measured once per sample, repeated if the value is more than 0.1 g/cm ³ from the table.
Comparison	Measured station densities versus the data table; the group's ranking versus other groups' rankings.

Student procedure

1. Read the design brief on the recording sheet: the spoon will rest in a pot of melted wax or chocolate at up to 90 °C, be washed in hot soapy water, sit near a stove burner, have a volume of about 30 cm³, and be sold in a low-cost kit. Underline every requirement.
2. Data lead: for each of the seven materials, compute the spoon's mass (density × 30 cm³) and its material cost (mass in kg × cost per kg). Write both in the screening table.
3. Screener: apply the three must-pass criteria to every material. Criterion 1: must not melt or soften below 120 °C. Criterion 2: must not dissolve in hot water or soak up enough water to swell or stay damp (a material that absorbs only a little, like nylon, passes; wood does not). Criterion 3: spoon mass must be 250 g or less. Mark pass or fail for each and write which property caused any fail. A material that fails any one criterion is out, no matter how good it is elsewhere.
4. Scorer: for the survivors only, score four criteria from 3 (best) to 1 (worst): lighter is better, cheaper is better, not burning in a stove flame is better, and a handle that stays cool (does not conduct heat quickly) is better. Total the scores.
5. Station tester (while steps 2 to 4 run): measure the density of the steel bolts, the PP caps and the wax chunk by water displacement in the 100 mL cylinder (push floating samples fully under with the wire; read the rise). Measure the pine block with the ruler instead (length × width × height) because it soaks up water. Weigh each sample and compute density; compare with the table.
6. When called, bring the PP cap and the wax chunk to the teacher's hot-water station. Watch for two minutes as the teacher places both in 80 °C water with tongs. Record what happens to each.
7. As a group, compare the station results with the table. Did the measured densities match within about 0.1 g/cm³? Did the hot-water test agree with the melting or softening column?
8. Decide. Write the group's recommended material, the two strongest reasons from the data, and the trade-off the chosen material still has. Then sketch a two-material spoon that fixes that trade-off, labeling which material goes where and which property of each you are using.
9. Clean the station: dry the samples, return them to the kit, empty and rinse the cylinder, wipe the bench. Answer the analysis questions individually.

Expected observations

- Screening: wax (softens about 55 °C), PLA (softens about 60 °C) and pine (soaks up water) fail; aluminum (81 g, about \$0.24), stainless steel (237 g, about \$0.95), polypropylene (27 g, about \$0.05) and nylon (34 g, about \$0.17) survive.
- Scoring with equal weights usually puts polypropylene or aluminum first, stainless steel last among survivors because of mass and cost; nylon is middle on everything.
- Station densities: steel bolts about 7.8 g/cm³, PP caps about 0.9 (they float and must be held under), pine about 0.4 to 0.55 by ruler, wax about 0.9 (floats, held under). The wax chunk softens and melts into a floating clear puddle in 80 °C water within a minute; the PP cap is unchanged.

Likely difficulties

- Converting grams to kilograms for the cost: a 237 g spoon is 0.237 kg, and students often multiply 237 by the price per kilogram and get a spoon that costs hundreds of dollars. Have the data lead sanity-check every cost against 'is this a cheap kit?'
- Scoring a material that failed the screen anyway; the screener and scorer should work from the same survivor list.
- Trapped air under bottle caps makes the water rise too much; tilt the caps as they go under and tap the cylinder.
- Reading the pine block's edges as whole centimeters; a 1 mm error on a 2 cm edge is 5 percent, so measure to the millimeter.
- Treating 'conducts heat quickly' as a reason a metal spoon is better for stirring, which it is, while ignoring that the handle gets hot; let groups argue this, since it is the real trade-off.

Structured debrief

1. Collect each group's recommendation on the board with its total score. Expect a split between polypropylene (light, cheap, cool handle, but it burns) and aluminum (does not burn, light, cheap, but the handle gets hot). Ask what the split reveals: the scored criteria were weighted equally, and a company that cares most about fire safety would weight flammability higher. Different weights, different winner, same process.
2. Ask which materials the screen removed and why: wax and PLA because they soften below 120 °C, pine because it soaks up water. Point out that wax scored best on three criteria and was still out; a must-pass criterion cannot be bought back with points.
3. Pool the station densities. Steel and wax usually land within 0.1 g/cm³ of the table; pine often reads low or high because blocks are not perfectly rectangular and softwood varies; PP reads high if air was trapped under the caps. This is why engineers test samples rather than trusting a table for a final decision.
4. Close on the two-material spoon. Most groups draw a stainless or aluminum bowl with a polypropylene handle, which is close to what real kitchen tools do. Ask which property of each material the design uses, and note that combining the best characteristics of two solutions is itself an engineering practice.

Recording sheet: what students fill in

Lab 2 recording sheet: Pick the spoon

Design brief — A company sells a kit for melting candle wax and chocolate in a pot on the stove. The kit needs a stirring spoon. The spoon rests in melted wax or chocolate at up to 90 °C, is washed afterward in hot soapy water, sits beside a stove burner, has a volume of about 30 cm³, and must keep the kit cheap. Choose the material.

Property data for seven candidate materials (rounded teaching values)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Material	Density (g/cm ³)	Melts or softens at (°C)	Dissolves in or soaks up water?	Burns in a stove flame?	Conducts heat quickly?	Cost (\$ per kg)
Aluminum	2.70	660	No	No	Yes	3
Stainless steel	7.9	about 1400	No	No	Yes, but slower than aluminum	4
Polypropylene (PP)	0.90	about 160	No	Yes	No	2
PLA plastic	1.24	softens about 60	No	Yes	No	4
Nylon	1.14	about 220	Soaks up a little	Yes	No	5
Pine wood	0.50	does not melt; chars above about 250	Soaks up water	Yes	No	1
Paraffin wax	0.90	about 55	No	Yes	No	2

This is a teaching dataset: densities and temperatures are rounded from reference values, and the costs are rough approximations that change with the market.

Step 1: screen every material (must-pass criteria)

Material	Spoon mass (g) = density × 30	Cost per spoon (\$)	C1: stays solid above 120 °C?	C2: no dissolving or soaking?	C3: mass 250 g or less?	Still in? (property that failed, if any)
Aluminum						
Stainless steel						
Polypropylene (PP)						
PLA plastic						
Nylon						
Pine wood						
Paraffin wax						

Step 2: score the survivors (3 = best, 2 = middle, 1 = worst)

Surviving material	Lighter is better	Cheaper is better	Does not burn is better	Cool handle (poor heat conductor) is better	Total

Verification station: does the table hold up?

Sample	Mass (g)	Volume method (water rise or ruler)	Volume (cm ³)	Measured density (g/cm ³)	Table value	Within 0.1?
Steel bolts					7.9	
PP caps					0.90	
Pine block					0.50	
Wax chunk					0.90	

Hot-water test (teacher station, about 80 °C, two minutes)

Sample	Before	After 2 minutes	Agrees with the 'melts or softens' column?
PP cap			
Wax chunk			

1. Our recommendation: name the material, give the two strongest reasons from the data, and state the trade-off this material still has.

Answer: Most groups: polypropylene (27 g spoon, about \$0.05, handle stays cool; trade-off: it can burn if it touches the burner flame, and 160 °C is not a huge margin above 90 °C) or aluminum (81 g, about \$0.24, does not burn, melting point far above the pot; trade-off: the handle gets hot because aluminum conducts heat quickly). Nylon is an acceptable third answer (34 g, about \$0.17, cool handle; trade-off: burns and soaks up a little water). Stainless steel is defensible only with a stated weighting toward durability (trade-offs: 237 g and about \$0.95).

Why: Any survivor can be recommended if the reasons come from the data and a genuine trade-off is named. The key judgment is that no material wins every criterion.

- Names a material that survived the screen
- Two reasons that cite values from the table
- A trade-off that is real for that material

2. Which material was eliminated by the screen even though it had the best score on at least two of the scored criteria? Which property eliminated it?

Answer: Paraffin wax (or pine wood). Wax would score best on mass (27 g), cost (about \$0.05) and cool handle, but it softens at about 55 °C, below the 90 °C pot, so criterion 1 eliminated it. Pine would score best on mass (15 g) and cost (about \$0.015) and cool handle, but it soaks up water, so criterion 2 eliminated it.

Why: Either answer shows the student understands that a must-pass failure overrides scoring.

Also acceptable: Accept PLA with the reasoning that it scores well on cool handle and reasonably on mass but softens at about 60 °C.

-  Sketch a spoon made of two materials that fixes your recommended material's trade-off. Label which material forms the bowl and which forms the handle, and next to each label write the property from the table that you are using.

Answer: A spoon with a metal bowl (aluminum or stainless steel, using 'does not burn' and 'stays solid far above 90 °C') and a polypropylene or nylon handle (using 'does not conduct heat quickly' and 'light'). Some students invert it (plastic bowl, metal handle), which is weaker because the bowl is the part that touches hot wax and the burner.

Why: The drawing should pair each material with a property from the table, which is the combine-the-best-characteristics idea of MS-ETS1-3.

- Two materials labeled in sensible places
- A property from the table written beside each material
- The design addresses the trade-off named in q1

Analysis questions: answer key

3. Show the calculation for the stainless steel spoon's mass and its material cost. Does it pass criterion 3?

Answer: Mass = $7.9 \text{ g/cm}^3 \times 30 \text{ cm}^3 = 237 \text{ g}$. Cost = $0.237 \text{ kg} \times \$4 \text{ per kg} = \$0.95$ (about 95 cents). It passes criterion 3 because 237 g is less than 250 g, though only just.

Why: Checks the density $\times$ volume step and the grams-to-kilograms conversion.

Also acceptable: Accept 240 g and \$0.96 from rounding 7.9 to 8.

4. Why does the process screen on must-pass criteria before scoring? Give an example from this lab of a material that would have ranked near the top if it had been scored without screening.

Answer: A must-pass criterion describes something the spoon cannot work without; a high score elsewhere cannot make up for failing it. Scoring first would hide that. Example: paraffin wax would score 3 on mass, 3 on cost and 3 on cool handle, near the top, but a wax spoon would melt into the pot at 55 °C. Pine is a second example: lightest and cheapest, but it soaks up water.

Why: This is the systematic-process point of MS-ETS1-2: screen on constraints, then compare on criteria.

- Explains that a failed must-pass criterion cannot be offset by scores
- Gives wax, pine or PLA as a concrete example with its failing property

5. Pine wood is the lightest and cheapest material in the table, yet it was eliminated. Which property eliminated it, and why does that property matter for a spoon that is washed in hot soapy water?

Answer: Pine soaks up water (criterion 2). A spoon that absorbs water swells, holds soapy water and old wax or chocolate inside the wood, and cannot be cleaned properly; wet wood can also crack as it dries. The property is absorption of water, which is related to, but not the same as, solubility: the wood does not dissolve, but water gets into it.

Why: Students should connect the property to the use. The absorption-versus-solubility distinction is worth noting but not required.

- Names the water-soaking property as the reason
- Explains why absorbing water is a problem for a washed spoon

6. At the station, which sample's measured density was farthest from the table value? Suggest a reason connected to how you measured its volume.

Answer: Usually the pine block or the PP caps. Pine: the block is measured with a ruler, so a slightly rounded or uneven block gives a volume that is too large or small, and softwood density itself ranges from about 0.35 to 0.55. PP caps: air trapped under the caps when pushed under water raises the water level too much, so the volume reads high and the density reads low; or the caps are not fully submerged, which does the opposite.

Why: The point is to tie a mismatch to the volume method, not to blame the table.

Also acceptable: Accept wax if the chunk was small, since a 10 g chunk raises the water only about 11 mL and a 1 mL misread is 9 percent.

7. In 80 °C water the wax melted but the polypropylene cap did not change. Which property did that test check? Predict, with a reason, what PLA plastic would have done in the same water.

Answer: The test checked the melting or softening temperature. Wax (about 55 °C) melted in 80 °C water; polypropylene (about 160 °C) was far below its softening point, so it did not change. PLA softens at about 60 °C, so in 80 °C water it would go rubbery and bend, and a thin piece could deform, even though it would not run like the wax.

Why: Prediction from the table to a new case, using the same property.

- Names melting or softening point as the property tested
- Predicts that PLA softens or bends, with the 60 °C value as the reason

8. A classmate argues: 'Stainless steel is best because it has the highest melting point.' Use the full screen-then-score process to explain what this argument gets right and what it leaves out, and say what the two-material spoon in your drawing is trying to fix.

Answer: Right: stainless steel passes criterion 1 with the largest margin, does not burn, and does not soak up water, so it is a safe survivor of the screen. Left out: the screen only asks whether a material stays solid above 120 °C, and every survivor does, so having the highest melting point earns nothing extra; the scoring then counts mass (237 g, the heaviest survivor), cost (about \$0.95, the most expensive) and the hot handle (conducts heat), on which steel scores lowest. One impressive number does not decide a design; the process does. The two-material spoon keeps a metal bowl for its high melting point and non-flammability and adds a plastic handle for its low heat conduction and low mass, fixing the hot-handle and weight problems.

Why: Full credit needs the screen-versus-score distinction and the idea that a criterion already satisfied gives no further advantage.

- States what the melting-point argument gets right (passes the screen)
- States that the screen is pass/fail and that steel scores low on mass, cost or heat conduction
- Explains the two-material spoon in terms of properties from the table

Individual evidence of learning

Each student submits their own screening table, scoring matrix, station table, hot-water table, recommendation (q1), q2, the two-material drawing and written answers to q3 through q8. The screening table and q4 are the evidence for the systematic-process target; q3 is the evidence for the density calculation target.

Assessment criteria

Criterion	Proficient looks like
Calculations	Spoon masses and costs computed correctly for all seven materials (for example 237 g and about \$0.95 for stainless steel), units shown.
Systematic process	Screen applied to every material with the failing property named; only survivors scored; totals correct; recommendation follows from the matrix.
Reasoning about trade-offs	Recommendation states a real trade-off (flammability of plastic or hot handle of metal) and the drawing uses a property of each material to address it.
Verification	Station densities measured and compared with the table, with a sensible reason offered for any mismatch; hot-water observations correctly tied to the softening column.

Accessibility adaptations

- Provide the screening table with the spoon-mass column pre-filled for two materials as worked examples and the cost formula written at the top (mass in g ÷ 1000 × price).
- Offer the property table in large print with icons for the yes/no columns (a flame, a water drop, a heat arrow).
- Let a student who cannot handle the cylinder take the data lead or scorer role; a partner can call out the readings at the station.

- Accept the recommendation (q1) and q8 as a recorded spoken response, and allow the two-material spoon to be built from a steel spoon and a foam-wrapped handle instead of drawn.

Low-cost alternative

Run the decision part with the table alone and no station; it takes about 30 minutes. If a kettle is not available, drop the hot-water test and instead show students a wax chunk left on a sunny windowsill or near a warm lamp, which softens visibly. Bolts can be replaced by any dense steel hardware from a drawer.

Model limitations

The costs in the table are rough per-kilogram material prices and ignore manufacturing, which usually dominates the price of a spoon. 'Melts or softens at' mixes true melting points (metals, wax) with softening temperatures (plastics), which is the right engineering question but not the same property; and 'burns in a stove flame' is a simplification, since aluminum powder burns and thick wood resists ignition. The screen thresholds (120 °C, 250 g) are chosen for the activity. This activity has not been physically tested by the authors; station values are estimated from reference densities.

Teacher notes

Accept any survivor as the recommendation if the reasons cite table values and a real trade-off is named; the quality of the process matters more than the pick. Check the cost column first when a group's ranking looks strange, since the grams-to-kilograms slip is the most common error. If your station pine reads far from 0.50, tell students softwood varies and ask them to use the measured value; the table value is a teaching estimate.