



AI First Engineering

# FUNDAMENTALS OF AI-AUGMENTED ENGINEERING: A Conversational Approach

## CHAPTER 4

### LAB-4: Engineering Report Template

#### Fill to the Mark

*How do we find the crossing without walking the whole road — and how do we know a  
computed root deserves the word “guaranteed”?*

# Team Information

|                         |                      |
|-------------------------|----------------------|
| Team name / number      |                      |
| Team members            | 1)<br>2)<br>3)<br>4) |
| Date                    |                      |
| Section (if applicable) |                      |

**How to use this template:** *replace every gray italic guide with your team’s actual evidence and reasoning, insert your photographs, log, tables, plots, and code excerpts in the marked places, and delete nothing else. Concise evidence + engineering reasoning beats pages of polished prose. Your AI analyst may help assemble this report from your engineering record — Section 19 is where the humans take responsibility for it.*

## 1. Problem / Objective

*What engineering question did this investigation answer — first physically (bisection with water: +60 mL to the first crossing, then halved moves toward the target line), then computationally (locate the line as the root of  $f(h) = 0$  on the cup model)? What does “certified” add to “computed”? Two or three sentences.*

## 2. The Physical Activity — Rules & Roles

**The rules you bisected under** — *empty cup, ONE target line · +60 mL per trip until the level FIRST crosses the line · the previous (BELOW) and current (ABOVE) states form the bracket · next move = HALF the last interval, 30 mL, in the direction the observation demands · then 15, 7.5, 3.75 ... ADD if below, REMOVE if above (removed water into the station return cup) · two syringes (60 mL, 10 mL) chosen by the resolution the move needs · STOP when WITHIN the posted tolerance or when the syringe cannot resolve the next halving · success = correct logic + within tolerance + valid log + safe.*

| Role                          | Who (rotation) | What the role owned                                                   |
|-------------------------------|----------------|-----------------------------------------------------------------------|
| Runner / operator             |                | walked to the reservoir, drew the planned move                        |
| Syringe operator              |                | read the plunger, ADDED to the cup or REMOVED into the return cup     |
| Recorder / data engineer      |                | started every log row BEFORE water moved; kept the bracket column     |
| Quality / inspection engineer |                | called BELOW · ABOVE · WITHIN TOLERANCE after every move; called STOP |

Our plan, written before START (coarse step, halving sequence, who calls the sign):

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### 3. Assumptions

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*Documented with the problem — before the search and before the model. Complete the right column concisely; the last rows are for additional team assumptions.*

|                                                                                                                |  |
|----------------------------------------------------------------------------------------------------------------|--|
| Cup volume estimated from its nominal 16 oz before the activity (the calibrated target was unknown to us)      |  |
| The syringe scale reading is the volume actually added or removed (no drips, no residual)                      |  |
| BELOW / ABOVE / WITHIN is judged by eye against the line — a visual criterion with line thickness and meniscus |  |
| The cup interior is modeled as a frustum: straight tapered walls, flat bottom                                  |  |
| $r_b$ , $r_t$ , $H$ are measured with a ruler to the millimetre                                                |  |
| $V_{\text{target}}$ = the calibrated target-line volume posted by the instructor                               |  |
| The acceptance tolerance is posted with the calibration — never chosen by the team                             |  |
| Additional team assumption:                                                                                    |  |
| Additional team assumption:                                                                                    |  |

### 4. Apparatus, Setup & Safety

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- Red 16-oz soup cup with ONE target line · 60-mL syringe (scale step \_\_\_\_ mL) · 10-mL syringe (scale step \_\_\_\_ mL) · station return cup for removed water · reservoir distance  $\approx$  \_\_\_\_ m · ruler (mm)

- Anything nonstandard at your station (cup differs, line hard to see, reservoir path), noted for the class comparison:
- Safety acknowledgment — all members: walking only, never running · spills wiped at once · syringes below shoulder height · no drinking · removed water only into the station return cup, never the floor or the reservoir.    ☐ ACKNOWLEDGED (initials: \_\_\_\_\_)

### PHOTOGRAPH OF THE STATION

*Insert one photo — cup with the target line visible, the two syringes, the return cup, the log sheet in view*

**Caption:** *(what does this figure show, in one sentence?)*

## 5. Committed Predictions P1–P4

### RECORDED BEFORE THE FIRST MOVE — DO NOT EDIT AFTERWARD.

P1 — +60-mL additions we predict before the FIRST CROSSING of the line: \_\_\_\_\_

P2 — After the first crossing, physical halvings (30, 15, 7.5 ...) we predict we can perform before instrument resolution matters: \_\_\_\_\_. Reason: \_\_\_\_\_

P3 — Requested move size at which we predict the 60-mL syringe stops being adequate and the 10-mL takes over: \_\_\_\_\_ mL Reason: \_\_\_\_\_

P4 — Total physical operations (every ADD and REMOVE) we predict before the target is located to the posted tolerance: \_\_\_\_\_

*After Phase 4 — what did the evidence say about each prediction? Answer here; never edit the originals above.*

## 6. Operation Log — Every Move

*Copy or photograph your complete log — every move, in order. One row per move; the row is started BEFORE water moves. The log must visibly show +60 ... +60 → FIRST CROSSING → -30 → ±15 → ±7.5 → ... → STOP, and a reader must be able to reconstruct the bisection without asking you. Directions after the first -30 come from your observations — nothing is pre-filled.*

| Step | Cumulative (mL) | Move (mL) | ADD / REMOVE | Syringe | Observed: BELOW / ABOVE / WITHIN | Bracket [low, high] (mL) | Next half-step · decision / reason |
|------|-----------------|-----------|--------------|---------|----------------------------------|--------------------------|------------------------------------|
| 1    |                 | 60        | ADD          |         |                                  | —                        |                                    |
| 2    |                 |           |              |         |                                  |                          |                                    |
| 3    |                 |           |              |         |                                  |                          |                                    |
| 4    |                 |           |              |         |                                  |                          |                                    |
| 5    |                 |           |              |         |                                  |                          |                                    |

| Step | Cumulative (mL) | Move (mL) | ADD / REMOVE | Syringe | Observed: BELOW / ABOVE / WITHIN | Bracket [low, high] (mL) | Next half-step · decision / reason |
|------|-----------------|-----------|--------------|---------|----------------------------------|--------------------------|------------------------------------|
| 6    |                 |           |              |         |                                  |                          |                                    |
| 7    |                 |           |              |         |                                  |                          |                                    |
| 8    |                 |           |              |         |                                  |                          |                                    |
| 9    |                 |           |              |         |                                  |                          |                                    |
| 10   |                 |           |              |         |                                  |                          |                                    |
| 11   |                 |           |              |         |                                  |                          |                                    |
| 12   |                 |           |              |         |                                  |                          |                                    |
| ...  |                 |           |              |         |                                  |                          |                                    |

+60 steps to the first crossing: \_\_\_\_\_ Halvings performed: \_\_\_\_\_ Total moves: \_\_\_\_\_  
 Final bracket: [ \_\_\_\_\_ , \_\_\_\_\_ ] mL Final cumulative volume at STOP: \_\_\_\_\_ mL

Stopping reason: WITHIN the posted tolerance ☐ instrument could not resolve the next halving ☐  
 TA inspection: log valid ☐ state within tolerance ☐

Gaps, odd moves, or procedure notes (nothing deleted — “—” marks a missing reading):

## 7. Debrief — DID WE JUST DO BISECTION WITH WATER?

### YES, IN LOGIC — WITH LIMITS. SHOW IT FROM YOUR OWN LOG.

For each element of the bisection logic, cite the row(s) of your log where it happened. Then, in the last column, say what limited the physical certificate at that step.

| Element of bisection                          | Where it appears in OUR log (row) | What we did | Physical limitation at this step |
|-----------------------------------------------|-----------------------------------|-------------|----------------------------------|
| First crossing — two states on opposite sides |                                   |             |                                  |
| Initial bracket [low, high]                   |                                   |             |                                  |
| First half-step (30 mL, opposite direction)   |                                   |             |                                  |
| Subsequent halving (15, 7.5, ...)             |                                   |             |                                  |
| An ADD / REMOVE decision from an observation  |                                   |             |                                  |
| A bracket update — the straddling pair kept   |                                   |             |                                  |

| Element of bisection            | Where it appears in OUR log (row) | What we did | Physical limitation at this step |
|---------------------------------|-----------------------------------|-------------|----------------------------------|
| The syringe-resolution decision |                                   |             |                                  |
| The stopping decision           |                                   |             |                                  |

*Distinguish, in two or three sentences: the algorithmic bisection LOGIC (which your log reproduces) from the physical uncertainty and actuator resolution (syringe scale and accuracy, retained droplets, transfer losses, meniscus and line-thickness judgment, cup geometry) that limit what the water can certify. Then Chapter 3 returns: the algorithm said HALVE AGAIN — when did the instrument say CAN I RESOLVE THAT? What drove the switch to the 10-mL syringe? Where did MATHEMATICAL resolution part from PHYSICAL resolution, and how did that decide the stop?*

## 8. The Calibrated Target — Our Bracket vs the Calibration

*Copy the instructor's posted calibration exactly, with units. These are the REFERENCE values for the rest of the report — a measurement with its own uncertainty, not the truth.*

|                                                                        |                                                                    |
|------------------------------------------------------------------------|--------------------------------------------------------------------|
| <b>TARGET LINE</b> $V_{\text{target}}$ [mL] (posted by the instructor) | _____ mL                                                           |
| <b>ACCEPTANCE TOLERANCE</b> [ $\pm$ mL] (posted with the calibration)  | $\pm$ _____ mL                                                     |
| <b>Our final physical bracket</b> [low, high] [mL]                     | [ _____ , _____ ] $\rightarrow V_{\text{target}}$ inside? YES / NO |
| <b>Our final cumulative volume at STOP</b> [mL]                        | _____ mL                                                           |
| <b>Difference: final volume – <math>V_{\text{target}}</math></b> [mL]  | _____ mL (within the posted tolerance? YES / NO)                   |

Where a difference could live (name the sources — syringe reading, drips, meniscus, line thickness, the calibration itself; do not decide which): \_\_\_\_\_

## 9. Cup Geometry + the Model $V(h)$ + Hand Check

**Frustum model** — the cup interior as a truncated cone: straight tapered walls between inner radius  $r_b$  at the bottom and  $r_t$  at the rim, inner depth  $H$ . Real cups are not frusta — the model is a stand-in, tested in Section 15.

$$V(h) = (\pi \cdot h / 3) \cdot (r_b^2 + r_b \cdot r_h + r_h^2), \quad r_h = r_b + (r_t - r_b) \cdot h / H$$

**Units** — radii and  $h$  in mm give  $V$  in  $\text{mm}^3$ ; divide by 1000 once, in one place, to get mL.

| Symbol          | Meaning                                                | Your value · units |
|-----------------|--------------------------------------------------------|--------------------|
| <b>r_b</b>      | inner radius at the bottom = inner bottom diameter / 2 | _____ mm           |
| <b>r_t</b>      | inner radius at the rim = inner rim diameter / 2       | _____ mm           |
| <b>H</b>        | inner depth, bottom to rim                             | _____ mm           |
| <b>h</b>        | water height above the inner bottom — the unknown      | _____ mm           |
| <b>V(h)</b>     | modeled water volume at height h                       | _____ mL           |
| <b>V_target</b> | calibrated target-line volume (Section 8)              | _____ mL           |
| <b>V(H)</b>     | brim-full model volume — must exceed V_target          | _____ mL           |

### HAND CHECK — ONE POINT, ON PAPER, BEFORE ANY CODE.

V(H/2) by hand:  $r_h = \text{_____ mm}$ ;  $V = \pi \cdot (\text{_____}/3) \cdot (\text{_____} + \text{_____} + \text{_____}) / 1000 = \text{_____ mL}$   
cup\_volume(H/2) in Python = \_\_\_\_\_ mL agree? YES / NO

## 10. WRITE IT — $f(h) = 0$ and the Sign

$$f(h) = V(h) - V_{\text{target}} \quad [\text{mL}]$$

Give each sign its physical meaning for THIS cup — the inspector's BELOW / ABOVE, now in millilitres of a model — then evaluate  $f$  at two heights and record the signs. Note the change of variable: this afternoon you bracketed in VOLUME (mL);  $f$  is a function of HEIGHT  $h$  (mm). Same logic, different units.

$f(h) < 0$  means: \_\_\_\_\_

$f(h) = 0$  means: \_\_\_\_\_

$f(h) > 0$  means: \_\_\_\_\_

$f(\text{_____ mm}) = \text{_____ mL}$  (sign \_\_\_\_\_)     $f(\text{_____ mm}) = \text{_____ mL}$  (sign \_\_\_\_\_)

Which crossing does the decision need, and how many are there? \_\_\_\_\_

## 11. TRAP IT — the Certified Bracket

The cage comes from physics; the certificate comes from two evaluations; continuity and the single crossing come from understanding the model. All three go in the record. Compare with Section 6: there the bracket was two straddling VOLUMES with an instrument behind them; here it is two HEIGHTS with a theorem behind them.

|                                                 |                                                             |
|-------------------------------------------------|-------------------------------------------------------------|
| <b>Bracket [a, b] [mm]</b>                      | [ 0 , _____ ] (a = empty cup, b = brim-full)                |
| <b>f(a) = [mL]</b>                              | _____ sign _____                                            |
| <b>f(b) = [mL]</b>                              | _____ sign _____                                            |
| <b>Sign change certified (f(a)·f(b) &lt; 0)</b> | YES / NO    in code: <code>assert f(a) * f(b) &lt; 0</code> |

|                            |                                              |
|----------------------------|----------------------------------------------|
| Continuity of f — why      | V(h) is a polynomial in h: _____             |
| Exactly one crossing — why | more height never means less water:<br>_____ |

What this certificate promises: at least one root of the MODEL lies in  $[a, b]$ . What it does not promise: anything about the real cup, the ruler, the calibration, or the units.

## 12. Three Halvings by Hand

**NO AI, NO PYTHON, NO EXCEL — YOUR GEOMETRY, YOUR ARITHMETIC, YOUR JUDGMENT.**

| n | midpoint m (mm) | V(m) (mL) | sign of f(m) | bracket kept (mm) | half-width (mm) |
|---|-----------------|-----------|--------------|-------------------|-----------------|
| 1 |                 |           |              |                   |                 |
| 2 |                 |           |              |                   |                 |
| 3 |                 |           |              |                   |                 |

After three halvings we can already guarantee:  $h^* = \text{_____} \pm \text{_____} \text{ mm}$  (compare with Section 14 rows 1–3: agree? YES / NO)

## 13. Requirement → Tolerance → Predicted n

The tolerance is derived from the posted acceptance tolerance — never chosen. The requirement is a VOLUME; converting it to a height tolerance through the cross-section at the line is engineering, and it happens before the loop runs.

| Step                       | What you compute                                                                               | Your value            |
|----------------------------|------------------------------------------------------------------------------------------------|-----------------------|
| ① Requirement (GIVEN)      | $\Delta V_{\text{allowed}}$ = the posted acceptance tolerance on the target volume (Section 8) | $\pm \text{_____ mL}$ |
| ② mL per mm at the line    | $A \approx \pi \cdot r_h^2 / 1000$ , with $r_h$ at the hand-halving bracket (mL/mm)            | $\text{_____ mL/mm}$  |
| ③ Height tolerance         | $\text{tol}_h = \Delta V_{\text{allowed}} / A$                                                 | $\text{_____ mm}$     |
| ④ Halvings needed          | smallest n with $W_0 / 2^{n+1} \leq \text{tol}_h$ , $W_0 = b - a$                              | $n = \text{_____}$    |
| ⑤ Model evaluations, total | n midpoint runs + 2 endpoint checks                                                            | $\text{_____}$        |

Who owns the tolerance, and why is it not a Python setting?

## 14. Excel / Python Bisection + Iteration Log

Paste the smallest excerpts that show your implementation — the Excel rows with the IF decision exposed and/or the Python loop with its printed log. Then complete the log table from your own run.

```
# cup_volume(h, rb, rt, H) — mm in, mL out; must reproduce the Section 9 hand check
```

```
# f(h) = cup_volume(h, rb, rt, H) - V_target;  assert f(a) * f(b) < 0;  while (b - a)/2 > tol_h: ...  stop on WIDTH, never on a count
```

### PASTE YOUR EXCEL TABLE OR PYTHON OUTPUT SCREENSHOT HERE

*Your own session — the iteration rows and the final line “n halvings: h\* +/- half-width” visible*

| n   | a (mm) | b (mm) | m (mm) | sign f(m) | half-width (mm) |
|-----|--------|--------|--------|-----------|-----------------|
| 1   |        |        |        |           |                 |
| 2   |        |        |        |           |                 |
| 3   |        |        |        |           |                 |
| 4   |        |        |        |           |                 |
| 5   |        |        |        |           |                 |
| 6   |        |        |        |           |                 |
| 7   |        |        |        |           |                 |
| 8   |        |        |        |           |                 |
| ... |        |        |        |           |                 |

Predicted n (Section 13): \_\_\_\_\_ Run n: \_\_\_\_\_ agree? YES / NO REPORT: h\* = \_\_\_\_\_ ± \_\_\_\_\_ mm (midpoint ± final half-width, digits justified by the bound)

Can every team member explain the code used in the submitted analysis? YES / NO

## 15. TRUST IT — the Measured Line + the Contract

Measure the real height of the target line on your cup (ruler standing inside, from the bottom). Compare with  $h^* \pm$  bound. Then sort any disagreement by source — the bisection bound covers the computation only.

Measured line height h<sub>measured</sub> = \_\_\_\_\_ mm Computed h\* = \_\_\_\_\_ ± \_\_\_\_\_ mm  
Gap = \_\_\_\_\_ mm larger than the bound? YES / NO

| Source of disagreement                       | Could it produce THIS gap? | Evidence / estimate | What the bisection guarantee says about it |
|----------------------------------------------|----------------------------|---------------------|--------------------------------------------|
| Numerical — the bisection bound              |                            | ± final half-width  | covered — this is the promise              |
| Model shape — straight walls assumed         |                            |                     | not covered                                |
| Geometry measurement — diameters, depth      |                            |                     | not covered                                |
| Calibration — the posted V <sub>target</sub> |                            |                     | not covered                                |

| Source of disagreement       | Could it produce THIS gap? | Evidence / estimate | What the bisection guarantee says about it |
|------------------------------|----------------------------|---------------------|--------------------------------------------|
| Units — mm <sup>3</sup> , mL |                            |                     | not covered                                |

#### THE CONTRACT — conditions checked

- ① Certified sign change —  $f(a)$ ,  $f(b)$  shown, assert present:
- ② Continuity of  $f$  — argued from the model form:
- ③ The right root — the crossing this decision needs, and why it is the only one:
- What the guarantee does NOT establish (model · parameters · units · measurements · physical validity) — in your words:

Known case:  $V(h^*) =$  \_\_\_\_\_ mL vs  $V_{\text{target}} =$  \_\_\_\_\_ mL → within  $\Delta V_{\text{allowed}}$ ? YES / NO

## 16. AI Analysis + BREAK THE AI — Audit the Guarantee

At least ONE evaluated AI claim from your workspace, plus the planted BREAK THE AI claim from the lab deck. Quote concisely — do NOT paste conversations. Attack the CONTRACT, not the syntax.

| AI claim (quoted concisely) | Verdict — ACCEPT / MODIFY / REJECT | Which condition or evidence decided it? | What changed, if anything |
|-----------------------------|------------------------------------|-----------------------------------------|---------------------------|
|                             |                                    |                                         |                           |
|                             |                                    |                                         |                           |

**BREAK THE AI** — “I ran bisection on  $[0, 100 \text{ mm}]$  for 10 iterations and found the line at  $h = 82.71 \text{ mm} \pm 0.01 \text{ mm}$ , guaranteed by the bisection theorem — the mark can be placed with certainty.” At least THREE attacks. “The claim survived” is a finding too — show HOW you verified each condition.

| Attack / question | What a certified root needs | Your evidence | Finding | Verdict |
|-------------------|-----------------------------|---------------|---------|---------|
|                   |                             |               |         |         |
|                   |                             |               |         |         |
|                   |                             |               |         |         |
|                   |                             |               |         |         |

#### The REWRITTEN claim — your certified version:

“Bracket  $[0, \text{_____}]$  certified ( $f = \text{_____}, \text{_____}$ );  $V(h)$  continuous, one crossing; after \_\_\_\_\_ halvings,  $h^* = \text{_____} \pm \text{_____} \text{ mm}$  (final half-width),

meeting the  $\pm \text{_____} \text{ mm}$  requirement derived from  $\pm \text{_____} \text{ mL}$ ;  $V(h^*) = \text{_____} \text{ mL} \approx V_{\text{target}}$ ; measured line \_\_\_\_\_ mm —

the \_\_\_\_\_ mm gap is attributed to \_\_\_\_\_, not to the numerical method.”

A confident root with no certified signs, no final width, and no requirement is not a guarantee; it is typography.

## 17. Final Certified Statement

“For our cup ( $r_b = \text{_____} \text{ mm}$ ,  $r_t = \text{_____} \text{ mm}$ ,  $H = \text{_____} \text{ mm}$ ) and the calibrated target  $V_{\text{target}} = \text{_____} \text{ mL}$ , we wrote  $f(h) = V(h) - V_{\text{target}}$  and certified the bracket  $[0, \text{_____}]$  ( $f = \text{_____}, \text{_____}$ ).

*$V(h)$  is continuous with exactly one crossing. The requirement  $\pm$  \_\_\_\_\_ mL at the mark gives tol  $h =$  \_\_\_\_\_ mm; bisection needed \_\_\_\_\_ halvings (predicted \_\_\_\_\_). Result:  $h^* =$  \_\_\_\_\_  $\pm$  \_\_\_\_\_ mm (midpoint  $\pm$  final half-width). Known case:  $V(h^*) =$  \_\_\_\_\_ mL. Measured line: \_\_\_\_\_ mm; the \_\_\_\_\_ mm gap is attributed to \_\_\_\_\_. Decision: the frustum model IS / IS NOT adequate for placing the target line on new cups of this type.”*

One concise line of evidence for each check:

- ① Certified sign change + continuity:
- ② Hand halvings agree with the Excel / Python log:
- ③ Predicted  $n =$  run  $n$ ; root reported as midpoint  $\pm$  half-width:
- ④ Known case + measured line + stated limitations:

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**A ROOT + ITS CERTIFICATE + ITS VALIDATION + A DECISION. A bare root is a guess wearing a theorem.**

## 18. Method Judgment + Limitations

- If the posted tolerance tightened tenfold: how many more halvings would the model’s bisection need — and could the physical bisection have followed, or would the syringe have hit its resolution wall first? Which limit is mathematical, which is physical?
- One limitation of the frustum model for this cup:
- One limitation of our measurement (ruler, line judgment, calibration, syringe reading):
- One more unit of engineering effort — where would it go? better geometry measurement · better calibration · a better cup model · more halvings · nowhere (already sufficient). Choice + reason:

## 19. Human Review & Approval

*“Before submission, we reviewed the completed report against our original engineering record — the operation log, measurements, calculations, code, tables, validation evidence, and conclusions. We accept responsibility for the submitted engineering work.”*

### Human reviewed and approved.

*This approval happens BEFORE FINAL SUBMISSION — after the completed report has actually been reviewed. Would you confidently put your name on this certified root? Sign only when the answer is yes.*

\_\_\_\_\_  
Name · Signature · Date

\_\_\_\_\_  
Name · Signature · Date

\_\_\_\_\_  
Name · Signature · Date

\_\_\_\_\_  
Name · Signature · Date

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**AI assists. Humans observe. Humans verify. Humans decide. Humans approve.**

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