Bacterium by Design Kit: Design a Bacterium, Question It, Measure What Was Learned

Introduction

In this 30-minute session, young people aged 12 to 17 design an engineered bacterium on paper to solve a real-world problem. Then each group acts as a risk committee that questions another group's design before both groups revise their own. A short questionnaire before and after measures what changed. We ran this activity in October 2026 with a Catalan scout group, in Catalan, with 45 participants in three age bands (12-14, 15-16 and 17), as part of our iGEM UPF 2026 project, Vinesys. The structure is the same for every age: what changes is the vocabulary, the number of part cards and the number of committee questions.

In this guide, you will find:

1. Driving question and objectives.
2. Session plan.
3. Organiser guide.
4. Information for organisers.
5. Materials and preparation.
6. Safety and ethics.
7. Tips from our session.
8. Evaluation.
9. Possible adaptations.
10. Build your own version.
11. Printables.
12. References and credits.

	Detail
Audience	Ages 12 to 17, in three age bands (12-14, 15-16 and 17). No biology knowledge needed.
Group size	10-25 young people per age band, working in groups of 4-5 (our bands had 22, 12 and 11 participants).
Duration	30 min per age band. We ran the three bands one after another.
Organisers	At least three: a facilitator, observers (one per two groups) and someone who collects and scores the questionnaires.

	Detail
Space	A room with tables for groups of 4-5. A projector helps; printed slides also work.
Cost	Printing and cutting only. No lab, no biological material and no devices.

Driving question and objectives

If you could design a bacterium to solve a problem, what could go wrong, and who should decide?

By the end of the session, participants will have:

1. Described a bacterium as a circuit of parts (sensor, processor, output and safety) and designed one for a real problem.
2. Named a concrete risk of their design and a measure that could reduce it.
3. Questioned another group's design and revised their own in response to a question.
4. Seen synthetic biology as something people design, test and decide about together, not only as something that happens in a lab.

The general and specific objectives, with the indicators we used, are in the Evaluation section.

Session plan

The session runs in six phases and changes format every 3-9 minutes. The same sequence is used for each age band.

Phase	Time	What happens
1. Pre-test	3 min	Participants answer an anonymous questionnaire alone and in silence.
2. Explanation	5 min	Five slides, each ending in a question to the room: parts, a worked example, risks and the challenge.
3. Design challenge	9 min	Groups of 4-5 draw a problem card and design a bacterium with part cards.
4. Risk committee	5 min	Two groups swap designs and question each other (2 + 2 min, plus 1 min to note changes).

Phase	Time	What happens
5. Review	4 min	Each group decides what to change and why. Two groups share with the room.
6. Post-test	4 min	Same questionnaire plus an exit question. Close with the open questions on the board.

The same session, adapted by age. The timing, the materials and the steps do not change. What changes is the level of abstraction:

	Ages 12-14	Ages 15-16	Age 17
Ideas and language	LEGO analogy: sensor = eyes, output = hand, safety = brake.	DNA → RNA → protein. A gene is a set of instructions; a promoter is the switch.	Inputs, logic (AND, NOT) and outputs. Every part has a cost for the cell.
Part cards	15 cards: sensors, outputs, safety and 1 blank.	17 cards: adds 2 promoters.	19 cards: adds a repressor (NOT) and an AND gate. Budget of 10 points.
Challenge rule	1 sensor, 1 output and 1 safety part.	1 sensor, 1 processor, 1 output and 1 safety part.	10 points. At least one of each type. An AND gate with 2 sensors is allowed.
Committee questions	3 questions.	6 questions.	9 questions (adds who decides, misuse and trade-offs).

Organiser guide

Phase 1: Pre-test (3 min)

Goal: get a baseline before anything is explained.

1. **Hand out the questionnaire (1 min).** Use the version for the age band (Printable 1). Participants write no name and no code. Tick PRE at the top.
2. **Read it aloud (30 s).** *"This is not a test. It helps us find out whether the activity works. If you don't know, tick 'I don't know': that helps us more than guessing."*
3. **Collect (1 min).** Cut at 3 minutes even if some are not finished, because a blank item is also data. Keep the sheets in a folder, uncorrected, and give no answers.

Why we did it this way: a pre-test taken before any explanation is the only way to show what the session added. The "I don't know" option stops guessing from hiding what participants do not know.

Phase 2: Explanation (5 min)

Goal: give just enough to design a bacterium and model asking before telling.

1. **Hook (30 s).** Show slide 1 and ask its question. Take answers by show of hands and write the jobs people mention on the board.
2. **Parts (1 min 15 s).** Slide 2: the parts of a bacterium as a circuit. Ask the question first, then explain, using the analogy of the age band (LEGO, DNA to protein, or inputs and logic).
3. **Worked example (1 min 15 s).** Slide 3: a bacterium that lights up with sugar. Ask what they would change so that it lights up only when there is a lot of sugar. Accept any reasonable idea and ask why.
4. **Risks (1 min).** Slide 4. Ask the question and take a vote (yes, no or it depends). Anyone who says it depends explains on what.
5. **The challenge (1 min).** Slide 5 shows the three steps, the times and the rules. Write the two questions you could not settle on the board as "open questions".

Why we did it this way: asking a conceptual question and letting people think before you explain is the core of peer instruction (Mazur, 1997). It also leaves room for dialogue instead of a lecture.

Phase 3: Design challenge (9 min)

Goal: apply the parts to a real problem and justify each choice.

1. **Form groups (1 min).** Groups of 4-5. Hand each group a part card set, a design sheet (page 1 of the group sheets) and a problem card drawn at random, face down.
2. **Design (8 min).** Each group reads its problem card aloud, picks the parts allowed for its age band, draws the circuit on the design sheet and writes why it chose each part and what could go wrong. Say: *"There is no correct answer, but there are defensible designs."*
3. **Circulate.** Only ask questions: "Why this part?", "What must it detect?", "What did you leave out?". Do not give designs. If a group finishes early, ask it to design the worst possible failure of its bacterium and how it would be noticed.

Why we did it this way: the challenge compresses the design, build, test, learn cycle that iGEM teams use onto paper: design now, test through the committee, learn in the review (Kolb, 1984).

Phase 4: Risk committee (5 min)

Goal: practise questioning a design for risk and defending or revising it.

1. **Pair the groups (30 s).** Each group swaps its design sheet with another group. Leave the committee slide projected.
2. **First round (2 min).** Group A inspects the design of group B with at least two questions from the committee card or the slide, and writes them on its committee sheet. Group B answers.
3. **Second round (2 min).** Swap roles.

4. **Note changes (30 s).** Each group writes on its review sheet any change it wants to make and which question prompted it.

Remind everyone: the questions are to understand and improve a design, not to attack it. "Yes, but…" is a valid answer.

Why we did it this way: a question from another group is what makes mutual learning visible: the design changes (or the group explains why it should not) because of what someone else asked.

Phase 5: Review (4 min)

Goal: make the changes, and the reasons for them, explicit.

1. **Fill in the review sheet (2 min).** Each group decides what changes, what does not and why, and writes a one-sentence summary of design v2.
2. **Share (2 min).** One group tells the room one change it made (30 s). Another tells something it decided not to change, and why. Defending a decision is also learning.

Phase 6: Post-test (4 min)

Goal: measure what changed and close the session.

1. **Hand out the same questionnaire (3 min).** Tick POST. It has one extra item: the exit question.
2. **Close (1 min).** *"The open questions on the board have no closed answer: they are for you to keep thinking about."*
3. **After you have collected the sheets,** go through any answers they ask about.

Information for organisers

You only need to understand five ideas to run the session well, even if you are not a biologist. It helps to read a little about ethics in synthetic biology so you can answer questions or conduct the conversation responsibly.

- **Synthetic biology** designs and builds new functions in living cells, much as an engineer designs a circuit. Teams work in cycles: design, build, test, learn.
- **A genetic circuit has parts.** A sensor detects something, a processor (a promoter, or a logic gate) decides when to act and an output does or signals something, such as a color, light or an enzyme. DNA holds the gene, RNA is the copy and the protein is the product.
- **Safety parts reduce the risk of escape:** dependence on a nutrient found only in the lab, a self-destruct gene, or a physical capsule. None is 100% reliable, because mutations can disable them.
- **Why it is debated:** a living organism released into the environment cannot be fully recalled. Open questions include whether it spreads, whether it passes its genes to other bacteria, who decides, and whether it could be used to cause harm (dual use).
- **Regulation:** in the EU, releasing a genetically modified organism into the environment requires a case-by-case authorisation (Directive 2001/18/EC), while work inside a lab falls under separate rules. Check the rules in your own country.

If a participant asks something you cannot answer, that is an important step: write it on the board as an open question.

Materials and preparation

Everything is printed on plain paper (thick paper is better for the cards). Setup takes about 20 minutes plus the time to cut the cards; a guillotine helps. The Printables section lists the files.

Per group:

Item	Quantity	Preparation	Printable
Part cards, common set	1 set	Cut along the dashed lines. Keep each set in an envelope or with a rubber band.	2
Promoter cards (ages 15-16 and 17)	1 set	Cut the two cards.	3
Repressor, AND gate and budget cards (age 17)	1 set	Cut only the row of cards. Give the price table whole.	4
Problem card	1, drawn at random	Cut the page into four. Repeat the page if you have more than 4 groups.	5
Group sheets	1 PDF per group	Page 1 is the design sheet (A3 if you can). Page 2 has the committee and review sheets.	6
Committee question card	1 (optional)	The same questions are on the committee slide.	7
Pencils and erasers	1 per person	-	-

Per participant: two copies of the questionnaire for their age band (PRE and POST), Printable 1.

For the room: a projector (or printed slides), a board or large paper for the “open questions”, a timer, a folder for the PRE sheets, scissors, and the tables arranged in groups of 4-5 before people arrive.

For the organisers: the organizer sheets (Printable 8) and the results workbook.

Preparation steps:

1. Run a 15-minute pilot with 4-5 people and note what to change (pilot record, Printable 8).
2. Tell the group leaders and the families that the questionnaires are anonymous and that you will take no identifiable photos.
3. Confirm how many participants and groups you have in each age band.

4. Print and cut the cards.
5. Assign roles: facilitator, observers (one per two groups) and collection and scoring.
6. Test the projector and the slides, or print them as a backup.

Safety and ethics

The activity is done on paper: there are no living organisms, no lab and no hazardous materials, so there are no biosafety requirements. The ethical points to care about are these:

- **Participants are minors.** Inform the group leaders and the families beforehand. The questionnaires are anonymous: no names and no codes.
- **Photos.** Take none in which a person can be recognised unless you have permission.
- **No promotion.** The goal is to teach and to open a dialogue, not to sell synthetic biology or your project. If someone asks about your project, answer briefly at the end.
- **Respect for opinions.** Nobody has to agree with the facilitator. Questions without a closed answer are part of the activity.

Tips from our session

1. **Pair the groups for the committee.** 7 of the 10 groups in our session changed their design after a question from another group.
2. **Ask before you tell.** Every slide ends with a question, and the board keeps the ones nobody can settle. It keeps the explanation short (5 minutes) and dialogue open.
3. **Give safety measures more attention.** Proposing a way to reduce a risk was our weakest result (2% to 47% of answers). If you want to improve it, before the challenge ask the room which safety card would stop each risk on slide 4.
4. **At age 17, give logic more time.** The AND-gate question did not improve in our session (45% before and after). A second worked example, or playing out the logic with the room, could help.
5. **Use one observer for every two groups.** Without observers you will not know whether a design changed, or why, and that is the main evidence of dialogue.
6. **Fill in the immediate record the same day.** The things participants said and what you changed on the fly are the first to be forgotten.
7. **Do not comment on the questionnaires early.** Go through the answers only once the POST sheets are in.

Evaluation

The aim of the evaluation is to show what participants learned and whether the dialogue actually changed designs. The table gives the objectives of the activity, the indicators we used and our results.

General objective	Specific objective	Indicator → our result
Give scout-group members aged 12 to 17 a hands-on way into how engineered bacteria are designed and what can go wrong, by having them design one themselves and defend it to their peers, in a 30-minute session adapted to each age group.	To describe a bacterium as a circuit of parts (sensor, processor, output, safety) and propose a design for a real problem.	The mean score on the 7-point test rises between the pre-test and the post-test, and open answers name both a sensor and an output → 2.24 to 5.07 on average (normalised gain 0.59, n = 45); answers naming both parts rise from 16% to 82%.
	To spot what could go wrong with a design and suggest a way to reduce it.	Open answers name a concrete risk and a measure tied to it, scored blind with a rubric → concrete risk 38% to 69% and mitigation 2% to 47%.
	To question each other's designs and change them in response.	Groups revise their design after the risk committee's questions, as recorded on the observation and review sheets → 7 of 10 groups (70%).

The questionnaire

Every participant fills in the same questionnaire before (PRE) and after (POST). It has seven items:

- Items 1 and 2 are identical for all age bands, so they can be compared.
- Items 3 and 4 are adapted to each age band.
- Item 5 is self-reported confidence (1 to 5).
- Item 6 is an open written answer, scored with the rubric below.
- Item 7 is an exit question, answered only in the POST. It is useful for quotes.

Each correct item among 1-4 is 1 point; “I don't know” and blank count 0. The total score is out of 7: items 1-4 (up to 4) plus the rubric (up to 3).

Age band	Item 1	Item 2	Item 3	Item 4
Ages 12-14	b	b	a	b

Age band	Item 1	Item 2	Item 3	Item 4
Ages 15-16	b	b	b	a
Age 17	b	b	b	b

Rubric for item 6 (the open question)

A rubric is a guide for scoring a written answer in the same way every time. Read the answer and ask three questions. Each “yes” is a 1 and each “no” a 0, giving 0 to 3 points.

Criterion	Give 1 point if the answer…	Counts	Does not count
Design	names a part that detects (sensor) and a part that signals (output).	“A gene that detects the poison and another that makes a color.”	“A gene that does it.”
Risk	names a concrete danger.	“If it escapes it could multiply.” “It could give a false positive.”	“It could go wrong.” “It could fail.”
Mitigation	proposes a measure tied to the danger it named.	“A switch so it dies if it leaves the spring.”	“We would be careful.”

Tips: score the PRE and POST sheets mixed together, without knowing which is which. If you hesitate between 0 and 1, choose 0. Two people should score five sheets separately and compare.

Using the results workbook

1. Enter one row per questionnaire sheet: age (12, 15 or 17), moment (1 = PRE, 2 = POST), the four letters of items 1-4 (for example bbab), the confidence number and the three 0/1 rubric scores for item 6. You do not type the written answer, only the scores.
2. On the Groups sheet, enter one row per group from the observation sheets: whether it changed its design and how many questions the committee asked.
3. The Summary sheet calculates the means, the group normalised gain, the percentage of correct answers per item, the rubric criteria and the dialogue indicator, with a chart.

The group normalised gain is (mean POST − mean PRE) / (7 − mean PRE): the share of the possible improvement that was achieved (Hake, 1998). It is fair between groups that start at different levels.

Reference results from our session

Indicator	Ages 12-14	Ages 15-16	Age 17	Total
Sheets PRE / POST (n)	22 / 22	12 / 12	11 / 11	45 / 45

Indicator	Ages 12-14	Ages 15-16	Age 17	Total
Mean score PRE → POST (0-7)	1.32 → 4.68	2.75 → 5.58	3.55 → 5.27	2.24 → 5.07
Group normalised gain	0.59	0.67	0.50	0.59
Item 1 (what is a gene)	9% → 73%	100% → 83%	82% → 91%	51% → 80%
Item 2 (key question)	36% → 68%	67% → 83%	82% → 100%	56% → 80%
Open answer with a design	14% → 68%	8% → 100%	27% → 91%	16% → 82%
Open answer with a concrete risk	32% → 73%	33% → 67%	55% → 64%	38% → 69%
Open answer with a mitigation	5% → 59%	0% → 33%	0% → 36%	2% → 47%
Mean confidence (1-5)	1.18 → 3.14	1.17 → 3.17	1.27 → 2.91	1.20 → 3.09
Groups that changed their design	4 of 6	2 of 2	1 of 2	7 of 10

Limits to state when you report

- There are no individual codes, so PRE and POST are compared as group means, not person by person. Report the number of PRE and POST sheets, because they can differ.
- The post-test is taken straight after the session: it measures immediate learning, not retention.
- There is no control group. With 10-20 participants per age band, the results are descriptive.

Possible adaptations

We only ran the session as described above. The changes below are suggestions that we have not tested.

Situation	Change
Fewer than 10 participants	Make two groups and pair them for the committee. One observer is enough.
More than 25 participants in a band	Add facilitators and run groups in parallel, or split the band into two sessions.
Mixed ages in one group	Use the version of the youngest participants and let the oldest take the committee role more often.

Situation	Change
Adults or older students	Start from the age 17 version and add a question about who decides and how.
Younger than 12	Start from the ages 12-14 version, with shorter questions and only the sensor, output and safety cards. Pilot it first.
Online	Show the part cards and sheets on a shared screen, work in breakout rooms and pair rooms for the committee.
No projector	Print the six slides for the age band, or draw the circuit examples on a board.
No color printer	Print in black and white. Every card has an icon and a label, so it is still readable.
Different problems	Replace the problem cards with cases from your own project (see the next section).

Build your own version

You can adapt this activity to any project in about two hours of preparation. The process is to turn a project into a design problem that a group can solve with a few parts and then be questioned about.

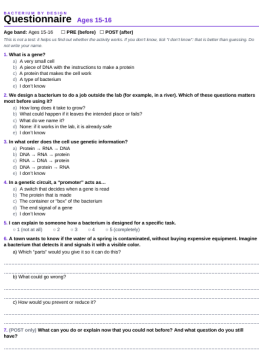
1. **Start from a problem.** Write a situation, what the bacterium must do and one open question about risk or who decides. Keep each card to three short blocks.
2. **Keep it one step away from your own project,** so participants can debate freely instead of judging your team. This also keeps the activity as Education rather than Human Practices.
3. **Choose the parts.** Four families are enough: sensors, processors, outputs and safety. Adjust the cards to your problems and give every card a short description.
4. **Write age-appropriate questions.** Start with what could go wrong or fail, add who is affected and who decides, and for the oldest add trade-offs and misuse.
5. **Keep the questionnaire identical before and after,** and write the rubric before you use it. Test it with a few people first.

Printables

All printables are in the zip **Bacterium_by_Design_Print_Ready.zip**. They are ready to print on A4 at 100% (do not choose “fit to page”). Cards are meant to be cut along the dashed lines.

#	File	What it is	Quantity
1	01_Questionnaire (one file per age band)	PRE/POST questionnaire. 1 page.	2 per participant (PRE and POST) plus spares
2	02_Part_Cards_Common_All_Ages	15 cards: sensors, safety, outputs and a blank card. 2 pages.	1 set per group
3	03_Part_Cards_Ages_15-17	The two promoter cards. 1 page.	1 per group of ages 15-16 and 17
4	04_Part_Cards_Age_17_and_Price_Table	Repressor, AND gate, budget card and price table. 1 page.	1 per group of age 17
5	05_Problem_Cards_All_Ages	Four problem cards. 1 page.	1 page per age band; repeat if more than 4 groups
6	06_Group_Sheets (one file per age band)	Page 1: design sheet. Page 2: committee sheet and review sheet. 2 pages.	1 per group
7	07_Committee_Question_Cards	Question cards for the three age bands. 1 page.	1 card per group (optional)
8	08_Organizer_Sheets	Observation sheet, immediate record and pilot record. 3 pages.	1 observation sheet per observer; 1 record per session; 1 pilot record

Files that come with the kit but are not printed: one slide deck for each age band (Bacterium_by_Design_Slides_Ages_12-14, Ages_15-16 and Age_17, PowerPoint, with speaker notes) and the results workbook (Bacterium_by_Design_Results_Workbook, Excel).



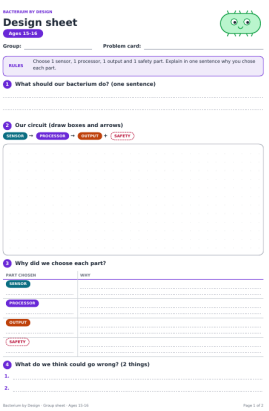
1. Questionnaire



2. Part cards



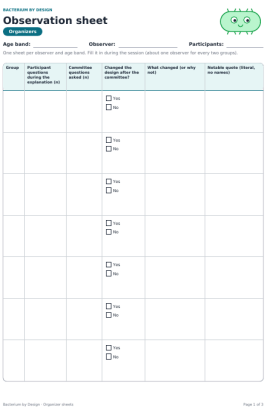
5. Problem cards



6. Design sheet







6. Committee and review sheets

7.Committee question cards

8. Observation sheet

References and credits

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Credits. Developed by the education group of the iGEM UPF 2026 team (Vinesys), Universitat Pompeu Fabra, Barcelona, and tested with a Catalan scout group. The card icons are from Font Awesome Free (CC BY 4.0, fontawesome.com). The activity follows the structure of our other kits, “A living sponge” and “Ethics role-play”.