CLOSING THE LABORATORY AUTOMATION EDUCATION GAP:

A White Paper on smartBench for Life Sciences Training

An open, modular, sterile robotic workstation concept for teaching reproducible laboratory automation.

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SiLA Rapid Integration

eu ROBOTICS

ADIRO Automation Didactic Robotic

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Learn more & get involved!

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1 Motivation: The Laboratory Automation Education Gap

Hands-on training gap

Life-science students rarely train with automated laboratory equipment, not to speak of robotic workcells. Engineering students lack hand-on experience with open automation standards, and reproducible digital workflows.

Transferability gap

Many academic automation setups remain expert-built prototypes that rely on tacit knowledge, custom interfaces, and site-specific calibration. Great research often drowns in the translational valley of death as timely, cost-effective scaling is still a huge hurdle for many.

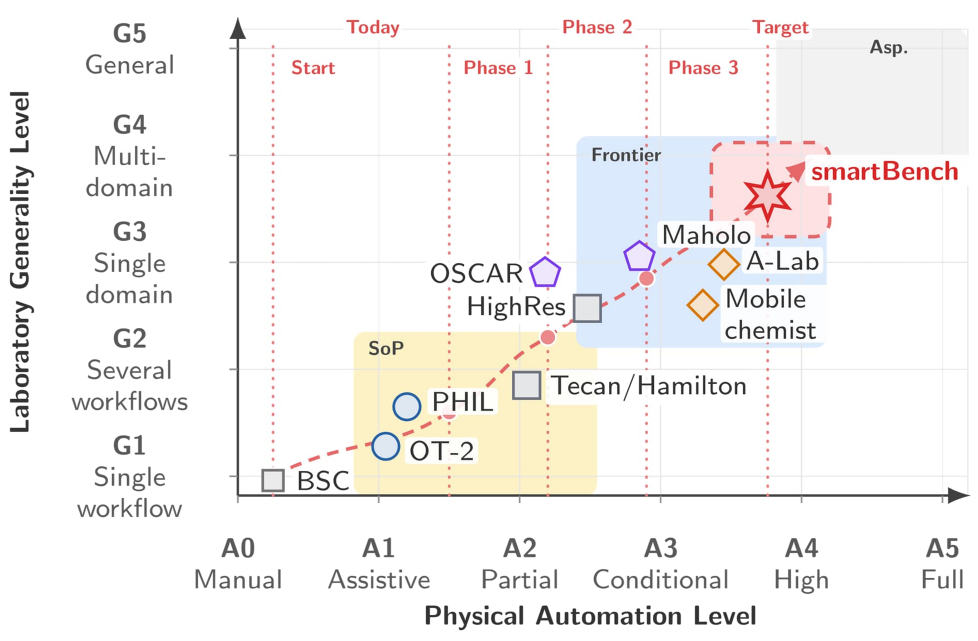
TRL gap

Bespoke systems often stall at TRL 3/4, while education needs transferable TRL 5/7 platforms validated in real lab environments. To onboard students and non-experts, the UX must be genuinely appealing. Design for beginners to win adoption. Neither academia nor SMEs can tackle all challenges alone and inter-disciplinary as well as academia-industry collaborations are essential.

smartBench response

smartBench proposes an open, modular and multi-purpose reference architecture that supports the transition from manual sterile work to validated robotic execution. It is cost-effective to be employed in engineering and life-science training alike and reliable for academic research and upscaling.

2 SMARTBENCH REFERENCE ARCHITECTURE

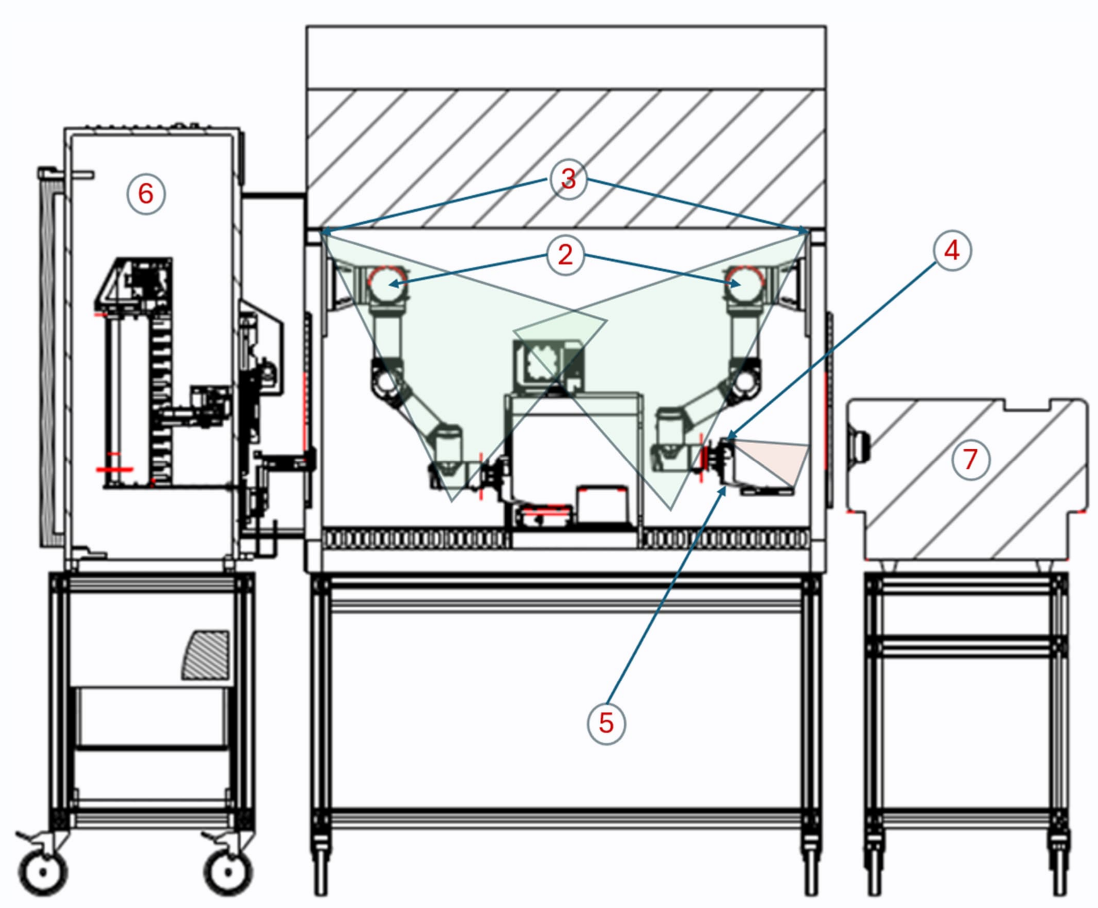


Automation–generality design space[1]

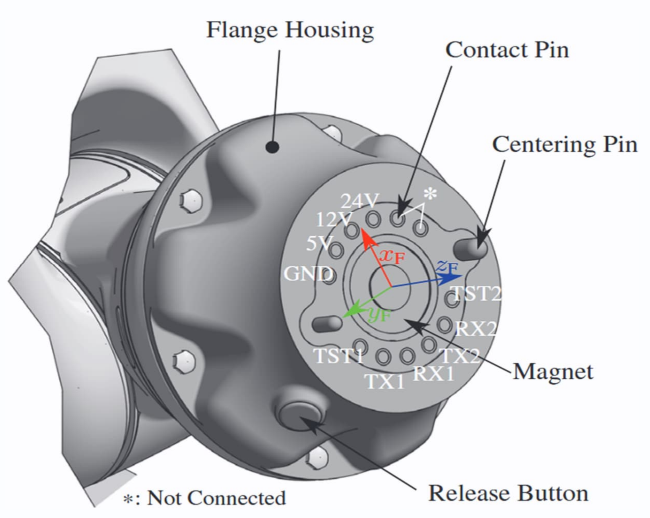
- Positions indicate approximate design-space regions, not benchmark scores.
- A0 reflects manual sterile-workbench baseline;
- A1–A5 and G1–G5 follow the original taxonomy by Angelopoulos[1].
- Marker styles distinguish representative platform classes, including BSC-based workbenches, liquid handlers, and autonomous laboratory systems.
- The dashed red path shows the proposed smartBench trajectory from manual BSL-2 work → A4/G4 operation.
- Broader G4 generality is a long-term aspiration rather than a current capability.

Abbreviations: BSC = biosafety cabinet; OT-2 = Opentrons OT-2; PHIL = Pipetting Helper Imaging Lid; OSCAR = Open-Source Collaborative Automation and Robotics; A-Lab = Autonomous Laboratory for Inorganic Materials Synthesis.

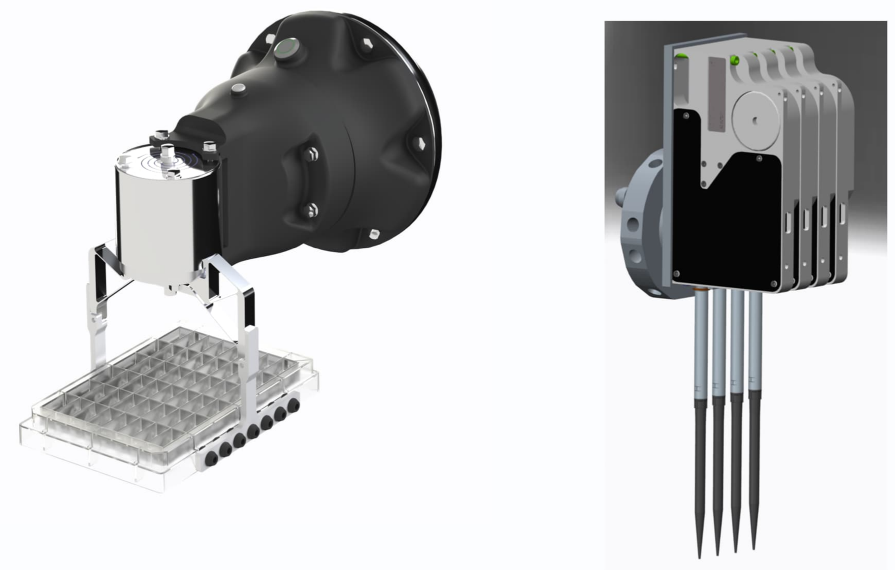
smartBench



Concept of smartBench: a modular robotic workbench combining a S2 laminar flow (**1**) and anthropomorphic dual robotic arms (**2**) with eye in-room (**3**) cameras for scene recognition and imitation learning. Eye-in-hand (**4**) equipped end effectors such as CrocoGrip (**5**) plate handling and Pipetting tools allow for precise and flexible visual servoing with sub-mm prcision. Smartlab can be flanged to existing equipment such as automated incubators (**6**) to microsopes (**7**) to create flexible setups from human-in-the-loop automation islands to full-fledged end-to-end automation systems suited for closed-loop agentic **D**esign-**M**ake-**T**est-**A**nalyse cycles



Standardized and cleanroom compliant automated tool-changer magnetic locking, integrated power, and serial communication for automated end-effector exchange. Fully sterilizable and w/o mechanical components



Reference plate- and liquid handling tools to cover the by far most-common tasks in cell culture. A compliant mechanism makes CrocoGrip[2] (left) robust and particle-emission free, and fully sterilizable. The envisioned multi-channel and reference pipette (right) shall cover volumes from 10µ to 5ml for media change and drug testing alike.

3 FROM HUMAN DEMONSTRATION TO VALIDATED ROBOT EXECUTION

Manual Demonstration multi-view camera observations → Object, pose, and Scene recognition → Semantic task description → Candidate task and motion prior behavioral initialisation → Validation Layer: Digital twin to check collisions, inter-locks and other constraints → Constraint-aware ROS2 execution, model based control and monitoring

smartBench learning-to-agentic-execution pipeline. Human demonstrations are abstracted into semantic scene representations and a generic protocol description that is transferable between machines. Tasks are then sensitized into a digital twin where all steps and movements can be simulated prior execution. All steps such as plate or liquid handling are compiled into SiLA2 commands and scheduled for autonomous execution.

Cost element	Cost	Role in replication model
Sterile workbench	8–20 k€	Enclosure and workcell
Static	1–2 k€	Add anchor plates, openings, and
2× Robotic arms	16–40 k€	Sample handling and manipulation
2× Standardized	1 k€	Automated flange for tool changing
4× Eye-in-room industrial cameras	2–4 k€	Error detection; imitation learning
AI-enabled computer	4–8 k€	General control, image analysis, voice UI, AI-based scene analysis
CrocoGrip end-effector for SBS	1 k€	Generic SBS plate handling
Assembly	1–20 k€	Cost for in-house DIY to
Total sum	**34–94 k€**	**Cost range**

4 References

[1] Angelopoulos et al., Science Robotics, 2024.
[2] Budde et al., Current Directions in Biomedical Engineering, 2022.

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Learn more & get involved!
Scan to visit the repository.