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SynLab: The Portable Lab

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Abstract

Introduction: Laboratory experiments are an important part of science learning, but access to practical experimentation is not always consistent. SynLab - The Portable Lab was developed in response to barriers identified around limited laboratory access, fixed schedules, safety concerns, and difficulty maintaining controlled conditions during practical work. The project proposes a portable, modular laboratory system designed to bring hands-on experimentation beyond a fixed laboratory environment. Its intended users include students, teachers, researchers, hobbyists and institutions. SynLab combines sensing, monitoring, observation and selected automation in one compact platform. An ESP32-based system connects sensors and experimental modules, while Web/Bluetooth control supports monitoring and interaction. The modular architecture allows experiment zones to be attached, rearranged and expanded. The research objective was to understand who uses laboratory facilities, how frequently experiments are conducted, what difficulties users experience, how accessible laboratories are when needed, and what stakeholders expect from a future portable laboratory system. Primary stakeholder research and secondary market observations were used to validate the problem and guide the design of SynLab.

Methodology:

Research design: The study used a problem-validation and prototype-development approach. Primary stakeholder research was combined with secondary market observations to understand laboratory usage, access, difficulties and expectations for a portable laboratory system.

Data collection: A stakeholder survey collected first-hand responses from people directly or indirectly involved in laboratory learning. The response set contained 65 participants for the main survey questions; the question on specific reasons for difficulties received 59 responses.

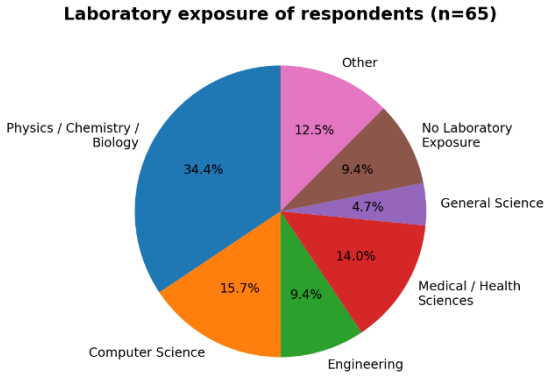
Stakeholder groups: The survey included students, teachers/educators, parents or guardians supporting practical learning, science hobbyists, institutional representatives and researchers.

Research objectives: The objectives were to identify laboratory users, understand experiment frequency, identify problems faced during laboratory work, assess laboratory accessibility when needed, and understand expectations from a future portable laboratory system.

Secondary research: Existing alternatives were reviewed, including traditional physical laboratories, virtual/simulation laboratories and remote laboratory platforms. The MarketMinds study also applied a CRAAP-test framework covering currency, relevance, authority, accuracy and purpose.

Prototype development: SynLab was designed as a modular system with a central hub and detachable experiment zones. A magnetic attachment system allows zones to detach for transport in a suitcase or bag. The pilot model integrates experimentation, observation, sensing, storage and selected automation.

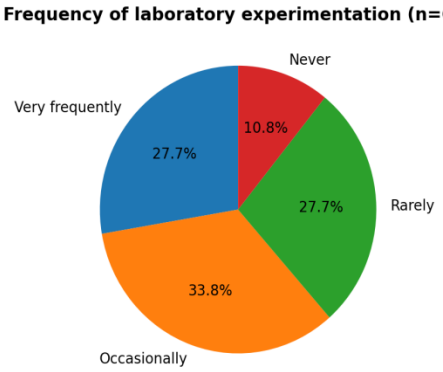
Technology: The project uses an ESP32-based control system with Wi-Fi/Bluetooth capability. The SynLab ONE specification identifies DHT22, MQ-135, BH1750 and DS18B20 as core sensors, alongside a Peltier module, water pump, OLED display, USB microscope and other actuators/modules.



The respondent pool covered multiple laboratory/education backgrounds, with Physics/Chemistry/Biology respondents forming the largest group (33.8%).

Results & Discussion:

Laboratory usage: The survey shows that laboratory engagement is present but uneven: 27.7% reported very frequent experimentation, 33.8% occasional experimentation, 27.7% rare experimentation and 10.8% no experimentation.



Experiment difficulties: Difficulty was widespread: 13.8% reported difficulties often and 50.8% sometimes. Together, 64.6% of respondents therefore reported facing difficulties at least sometimes, while 24.6% reported rarely and 10.8% never.

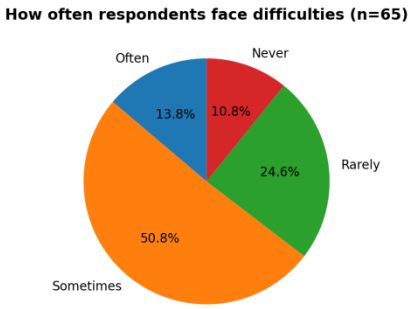


Figure 3. Frequency of difficulties during experiments

Main causes: Among the 59 responses to the specific-difficulties question, time constraints in lab sessions were the most frequently selected reason (32; 54.2%), followed by limited availability of equipment (30; 50.8%) and lack of clear guidance or instruction (25; 42.4%). Safety concerns and outdated/insufficient laboratory setups were each selected by 19 respondents (32.2%).

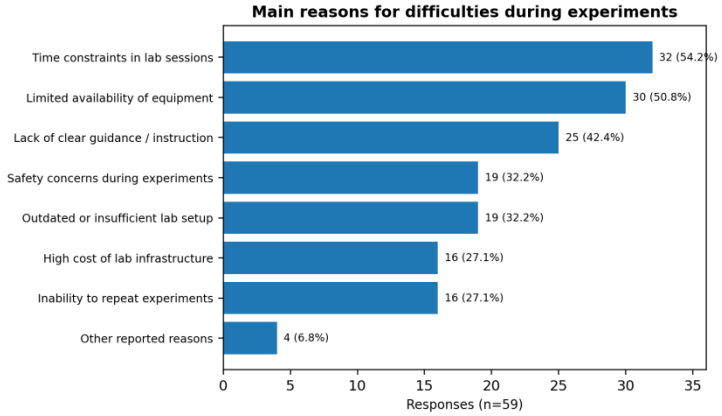


Figure 4. Main reasons for difficulties during experiments (multiple responses permitted)

Laboratory accessibility: Only 16.9% of respondents described laboratory facilities as easily accessible when needed. A further 55.4% reported accessibility with limitations, while 21.5% found laboratories difficult to access and 6.2% reported no access at all. Thus, 83.1% experienced some degree of access limitation.

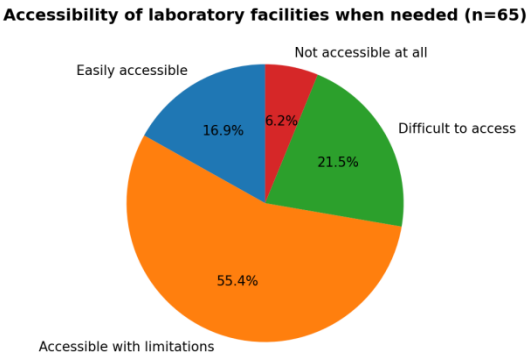


Figure 5. Accessibility of laboratory facilities when needed

Demand for a better system: Interest in a future laboratory system was strong. 66.2% rated such a system extremely helpful and 29.2% helpful, meaning 95.4% gave a positive response. Only 4.6% selected neutral and no respondent selected not helpful.

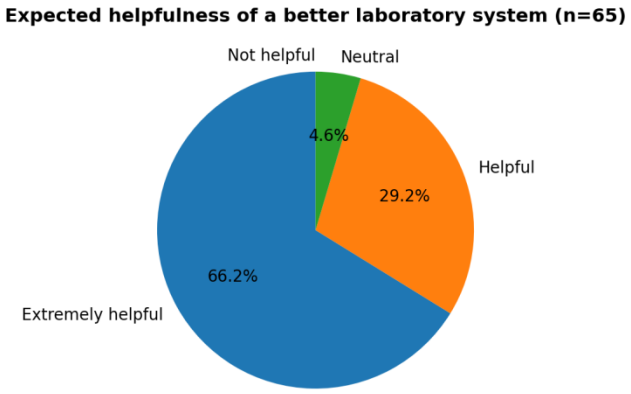


Figure 6. Expected helpfulness of a better laboratory system

Design implications: The survey's strongest signals directly informed SynLab's design direction: portability, safety, guided experimentation and ease of use. The findings support a system that can move beyond a fixed laboratory, provide controlled and monitored experimentation, and offer guidance without requiring the full infrastructure of a conventional laboratory.

Competitive context: Traditional physical laboratories provide hands-on experience but are constrained by location, time, safety risks and maintenance. Virtual or simulation-based laboratories improve accessibility but cannot provide equivalent

physical interaction. Remote laboratory platforms provide real equipment access but depend on complex infrastructure and reliable connectivity. SynLab is positioned as a complementary model addressing portability, flexibility, safety and guided experimentation.

Prototype outcome: The pilot model demonstrates a modular laboratory architecture with detachable zones, an ESP32-based controller, mounted sensors, a USB microscope and selected automation. The project presentation identifies a prototype-level SynLab ONE cost of approximately ₹3,000, with the major listed components including the stainless-steel structure, Peltier module, ESP32 controller, core sensors and water pump.

Evidence	Observed result	Implication for SynLab
Experiment difficulty	64.6% often/sometimes	Prioritize guided, safer and simpler experimentation.
Access limitation	83.1% have some access limitation	Portability and flexible access are central.
Positive demand	95.4% helpful/extremely helpful	Strong validation for a future portable system.
Top difficulty	Time constraints: 54.2%	Reduce dependence on fixed lab schedules.
Second-highest difficulty	Equipment availability: 50.8%	Provide compact, integrated equipment / modules.

Research limitation: The MarketMinds report notes that the survey size was limited and can be expanded further. Some responses were based on individual experiences. The findings are therefore used to validate the problem and guide prototype design rather than to claim statistical representation of all laboratory users.

Conclusion: The primary survey and secondary research identify a consistent gap in practical laboratory access. The strongest evidence is the combination of frequent experimentation difficulties, substantial access limitations and strong positive interest in a better laboratory system. SynLab responds with a portable and modular architecture

that combines hands-on experimentation with sensing, monitoring, observation, guidance and selected automation.

Future work. SynLab V2 / SynLab PRO is planned as an evolution toward a more capable portable research platform. Future development includes high-precision pH, turbidity, dissolved oxygen, temperature and conductivity sensing; chemical analysis for nitrates, phosphates and selected heavy metals; biological testing for bacterial contamination; AI-assisted sensor calibration; and expandable experiment modules. The long-term vision is for SynLab V2 to become an accessible, affordable and scalable real-world laboratory solution for learners everywhere.

Keywords: Portable laboratory, hands-on STEM education, laboratory accessibility, modular laboratory system, ESP32, environmental sensing, experimental learning, educational technology.

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