RESEARCH

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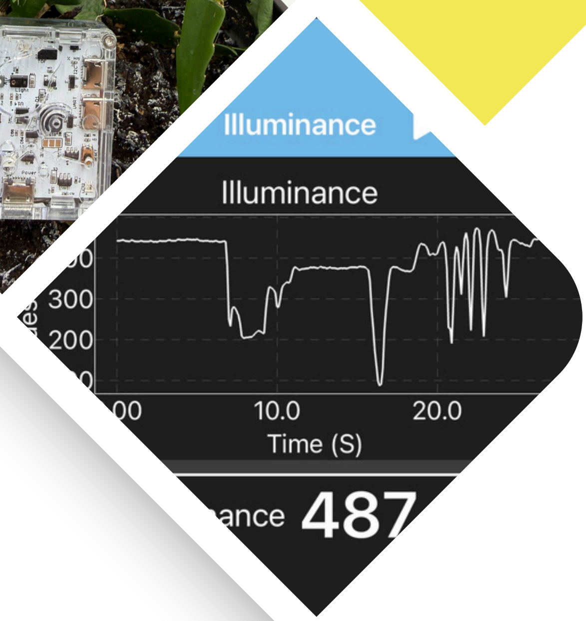
WATCH OR DO?

THAT IS THE QUESTION.

Live Data Collection vs. Virtual Simulations in K–12 Science Learning



Mission

The world is driven by data and we are driven to teach future generations how to use it for good. We create data powered technology and brilliant activities that empower students everywhere to think deeply, explore with passion, and solve our planetary scale challenges.

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Purpose

This brief summarizes education research comparing live data collection and analysis with virtual science simulations, focusing on student learning, engagement, and data literacy outcomes.

Key Findings from Education Research

Education research consistently shows that students learn science more deeply when they collect and analyze real-world data. While simulations are valuable instructional tools, studies indicate they are most effective when used alongside, not in place of, hands-on data experiences. When students work with live data, they must make decisions about what to measure, how to collect data, and how to interpret results that may not be perfect or predictable. These experiences help students understand that scientific data often includes variation and uncertainty.

Ukrainian students work together to collect temperature data resulting from friction.

Live data collection aligns more closely with how science is practiced and strengthens students' ability to reason from evidence, interpret graphs, and explain patterns using data. By analyzing data they collected themselves, students are more likely to connect abstract concepts to real-world phenomena. This process supports the development of data literacy skills that are essential across science, mathematics, and technology disciplines.

Why Live Data Collection Matters

Supports Authentic Scientific Practices

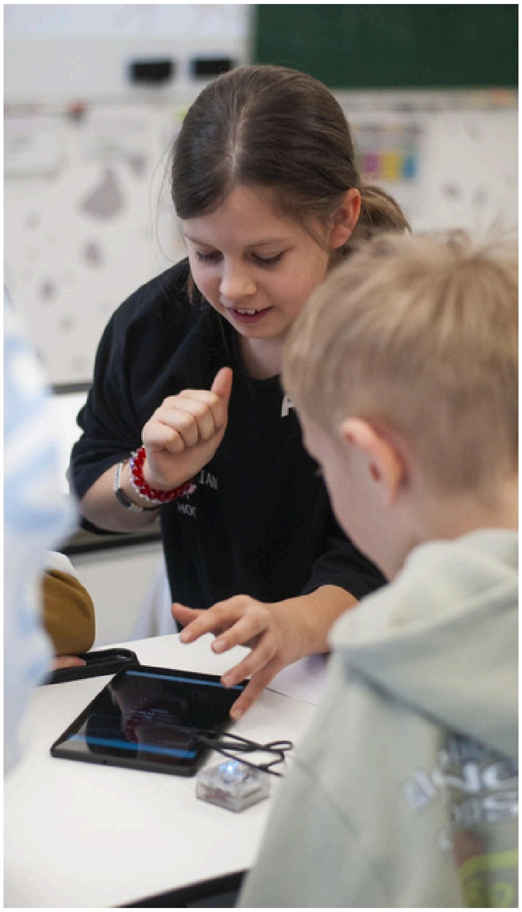
Students who collect their own data must make decisions about measurement, deal with imperfect results, and revise explanations based on evidence. These experiences closely match real scientific work.

Research by the National Research Council emphasizes that inquiry-based learning is strongest when students generate and analyze their own data.

Builds Stronger Conceptual Understanding

Research shows that students gain deeper understanding when they connect abstract concepts to physical measurements they collect themselves.

The National Academies of Sciences reports that active engagement with evidence significantly improves learning outcomes.



Students in Ukraine collaborate to collect and analyze light intensity data.

Develops Data Literacy and Graphing Skills

Sensor-based investigations help students:

- Interpret real graphs
- Recognize noise and variation
- Understand cause-and-effect relationships

These skills are essential for science, mathematics, and data science learning.

Studies published in the Journal of Research in Science Teaching highlight the importance of student-generated data for developing data reasoning skills.

Idaho charter school students collect CO_2 from a reaction in preparation for conducting sensor based experiments.

Increases Engagement and Motivation

Students are more engaged when data comes from their own bodies, classroom, or environment. When students create a reaction, observe changes, and capture data themselves, the learning experience becomes active rather than observational. This personal connection helps students stay focused and persist through challenges when results do not match expectations.

The International Society of the Learning Sciences documents higher engagement and stronger learning outcomes in experiential and embodied learning environments, where students interact directly with physical systems and connect their actions to measurable data.

Role of Simulations

Research does not suggest eliminating simulations. Instead, simulations are most effective when they:

- Prepare students for hands-on investigations
- Help visualize invisible processes
- Support reflection after live experiments

The strongest learning outcomes occur when simulations complement live data collection.

Students in Ghana visualize the invisible presence of CO2.

Comparison of Learning Outcomes

Learning Outcome	Live Data Collection	Virtual Simulations
Authentic scientific inquiry	High – mirrors real science practices	Moderate – processes are simplified
Data variability and uncertainty	Present and observable	Often minimized or removed
Student engagement	High – personal and contextual	Moderate – observational
Data literacy and graph interpretation	Strong – real, imperfect data	Limited – idealized data
Conceptual understanding	Deeper and longer-lasting	Effective for visualization
Preparation for real-world science	Strong alignment	Partial alignment

Summary

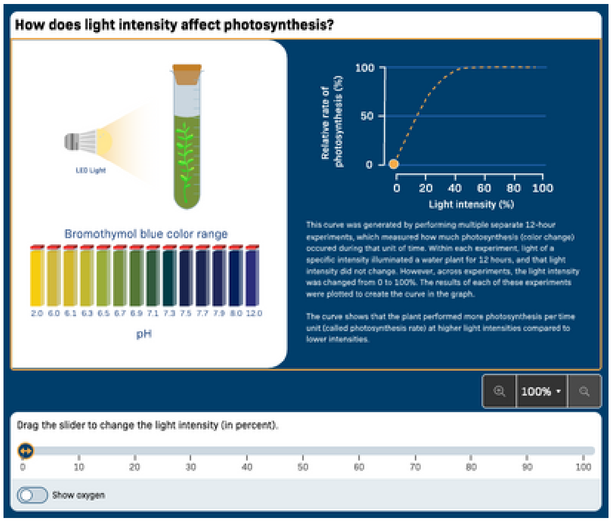
Research indicates that students develop stronger scientific reasoning, data literacy, and conceptual understanding when they collect and analyze real-world data. Virtual simulations are most effective when used to support—not replace—live data investigations.

Combining Simulations with Science in the Real World

Education research supports the use of both simulations and hands-on investigations, but it also makes clear that the strongest learning occurs when students move beyond virtual models and work with real data. Simulations are powerful for introducing concepts, visualizing processes, and testing ideas quickly. However, when students collect and analyze data from physical systems, they gain a deeper understanding of how science works, including variability, measurement limits, and cause-and-effect relationships. The following example illustrates how simulations can be effectively paired with live sensor-based investigations to support deeper, more authentic science learning.

Simulation: LabXchange – Light Intensity and Photosynthesis

This LabXchange simulation allows students to explore how changes in light intensity affect the rate of photosynthesis. In this virtual environment, students can quickly adjust variables, observe idealized outcomes, and identify general patterns. The simulation is effective for introducing the relationship between light energy and photosynthetic rate and for helping students visualize a process that is otherwise invisible.



However, the data produced in the simulation is clean and predictable. Students do not encounter sensor noise, environmental variation, or experimental constraints, and they are not required to design or carry out an investigation.

Hands-On Investigation: databot - The Oxygen Makers

In the following databot photosynthesis investigation, students generate oxygen through a real biological process and measure changes using live sensors. Students must set up the system, control light conditions, collect data over time, and interpret results that may vary between trials. This experience requires students to work with authentic data, recognize variability, and connect changes in light intensity to measurable biological outcomes.

By collecting their own data, students move from observing a modeled relationship to explaining real-world evidence. In the hands-on investigation, students measure changes as they happen, seeing how light affects a living system in real time. This experience reinforces the same core concept introduced by the simulation while also strengthening data literacy, graph interpretation, and scientific reasoning. Working with live data helps students connect abstract ideas to physical processes they can observe, measure, and explain using evidence.

Why the Combination Matters

By collecting their own data, students move from observing a modeled relationship to explaining real-world evidence. In the hands-on investigation, students measure changes as they happen, seeing how light affects a living system in real time. This experience reinforces the same core concept introduced by the simulation while also strengthening data literacy, graph interpretation, and scientific reasoning. Working with live data helps students connect abstract ideas to physical processes they can observe, measure, and explain using evidence.

Conclusion

Education research consistently shows that students learn science most effectively when they actively engage in collecting, analyzing, and explaining real-world data. While simulations play an important role in introducing concepts and visualizing processes, they are most powerful when paired with hands-on investigations that allow students to generate their own evidence. This combined approach reflects how science is practiced and supports deeper understanding of data, variability, and cause-and-effect relationships.

By using simulations to build conceptual understanding and live sensor-based investigations to test ideas with real data, educators can support stronger scientific reasoning, data literacy, and student engagement. Together, these tools create a balanced learning experience that moves students from observing science to doing science—preparing them with the skills needed to analyze evidence, think critically, and apply scientific knowledge in real-world contexts.

Appendix: The Research

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning.* Washington, DC: National Academies Press.

This report defines scientific inquiry as learning that requires students to collect, analyze, and interpret real-world data. It emphasizes that understanding variability and uncertainty is essential to authentic science learning. While simulations can support instruction, the report makes clear that observing pre-generated data alone is not sufficient. Meaningful inquiry occurs when students use tools and technologies to generate their own evidence and reason from data.

National Research Council. (2007). *Taking Science to School: Learning and Teaching Science in Grades K–8.* Washington, DC: National Academies Press.

This report emphasizes that young learners build scientific understanding by actively investigating phenomena and working with evidence they generate themselves. It highlights the importance of hands-on experiences for helping students connect observations, measurements, and explanations. While models and simulations are recognized as useful tools, the report stresses that they cannot replace direct interaction with physical systems. Learning is strongest when students engage in collecting, analyzing, and discussing real data.

Linn, M. C., & Eylon, B. S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration.* Journal of Research in Science Teaching,

This research highlights the role of student-generated data in helping learners integrate new ideas with prior knowledge. The authors note that working with real data supports deeper reasoning because students must interpret variability and resolve inconsistencies. While simulations can help visualize concepts, the study emphasizes that collecting and analyzing live data leads to stronger understanding. Technology is most effective when it supports hands-on investigation rather than replacing it.

National Academies of Sciences. (2018). *How People Learn II: Learners, Contexts, and Cultures.* Washington, DC: National Academies Press.

This synthesis of learning research shows that students learn more deeply when they actively construct knowledge through experience and evidence. The report explains that learning improves when students generate data, interpret results, and revise their thinking based on outcomes. Simulations can support understanding, but deeper learning occurs when students connect abstract ideas to real-world measurements. Active engagement with data is identified as a key driver of conceptual understanding and transfer.