Meeting the World's Needs for 21st Century Science Instruction

A SYNTHESIS OF RESEARCH AND BEST PRACTICES

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PASCO scientific

Table of Contents

Abstract

This paper draws upon a review of the research and expert opinion related to science education, the use of technology in the classroom and how instructional resources provided by PASCO can support science education initiatives.

Five key findings are reported: the worldwide need for qualified science, technology, engineering, mathematics (STEM) professionals; the necessity for “scientific literacy;” the role technology plays in deepening students’ understating of science concepts; how inquiry-based science can increase student motivation and interest in science; and examples of how PASCO technology has improved student understanding and engagement in science around the world.

Review of research from leaders in science education confirms the positive impact, value and efficacy of a technology-supported instruction. This paper examines the economic and social benefits for individual students, future workers and countries as reported from UNESCO, National Science Board, and the U.S Congress Joint Economic Committee. The call for students to be more “scientifically literate” and gain experience in the practice of doing science includes knowledge beyond the facts, but an understanding about the practices of science. Blending technology into data collection, analysis and visualization as part of an inquiry-based instruction has been shown to deepen understanding. Examples of how low-cost, hands-on experiences can support scientific understanding while stretching precious resources further are provided along with case studies of how this technology has improved student understanding and engagement in science are also provided.

Introduction

How can today's students gain the scientific know-how and experience they need to help their nations succeed in tomorrow's global economy? Countries throughout the world are looking for ways to improve their students' understanding of science and their motivation to learn more. Technology is an effective tool for achieving these goals—both of which can be promoted through hands-on, inquiry-based science instruction.

In particular, research evidence demonstrates that sustained, guided student use of technology tools for data collection, analysis, and visualization helps deepen students' understanding of science concepts, thus increasing scientific literacy while providing experiential knowledge of science practices. Research also suggests that such learning experiences help increase students' interest, motivation, and engagement in science.

This paper presents current, reputable research and expert opinion supporting these practices—together with examples of how these practices are enhanced through use of tools and resources developed by PASCO to support inquiry-based science instruction.

PASCO Products and Services

Since 1964, PASCO has been designing, developing, and supporting innovative science teaching and learning solutions for primary, secondary, and higher education. Today, teachers and students in more than 100 countries use PASCO solutions.

Specific resources offered by PASCO in support of primary and secondary science education include the following:

- Over 80 PASPORT digital sensors for real-world data collection in physics, biology, chemistry, and environmental science
- SPARKvue software, which integrates tools for students to take measurements, visualize and share data, reflect on their observations, create journals, participate in collaborative learning, and perform independent analysis
  - The SPARKvue environment offers a variable scaffold inquiry approach providing as much or as little support as the teacher determines is pedagogically appropriate—through display options, sensor settings, and optional teacher-authored instructions.
  - SPARKvue offers a full suite of options to display and analyze live sensor data, including line graphs, bar graphs, single-number measurements, tables, and meter displays.
  - SPARKvue provides students with access to science and engineering analysis tools, including statistical analysis (minimum, maximum, mean, standard deviation, and more); graphical analysis, including curve fits (regression analysis) and area under a curve; and a data processing calculator.
  - Students have the capability to annotate graphs with information and observations.
  - SPARKvue is available across a variety of technologies, including iPad, Chromebook, Android and Windows tablets, Mac and Windows laptops, and desktop computers.
- SPARKlabs—integrated, electronic labs that give teachers the ability to integrate science content with experimental procedure, live data collection and analysis, all within the SPARKvue environment. They cover the scope of science teaching from primary grades to university.

- Problem-based learning resources, including STEM modules featuring both software tools and instructional materials that integrate science, math, and technology in the context of an engineering challenge
- Teacher support, including detailed teacher manuals, guided-inquiry activities, background materials, tips, suggested answers, and other resources
- Professional development led by former science teachers, featuring modeling of how to guide students through a customizable lesson based on solid pedagogy and an inquiry-based approach

About This White Paper

This white paper includes the following informative sections:

- Top-level findings summarized from the body of research
- Discussion of the need for qualified science and technology professionals for tomorrow's economy and tomorrow's world
- Discussion of the need for scientific literacy and hands-on experience for all of today's students
- Summary of research about use of technology-supported inquiry to build scientific understanding
- Summary of research about use of technology-supported inquiry to build students' interest in science
- Three examples across the globe of promising implementations of inquiry-based science with technology tools
- Conclusion

Top-Level Findings

The following findings are supported by a review of research and expert opinion related to science instruction and the worldwide need for expanded scientific expertise—considered together with the capabilities and experiences of educators using tools and instructional resources provided by PASCO.

There is a worldwide need to develop more qualified scientists, medical professionals, engineers and technologists.

- Scientific expertise represents a key asset with economic and social benefits for individual countries and the world (Dobbs et al., 2012; OECD, 2013; UNESCO, 2010; U.S. Congress Joint Economic Committee, 2012).
- Scientific, mathematical, and technical expertise translates into benefits for students and future workers, with attending benefits for countries (Dobbs et al., 2012; National Science Board, 2014; U.S. Congress Joint Economic Committee, 2012).
- As the demand grows for qualified workers in STEM-related jobs, there are indications that supply may not be able to keep pace with demand (Dobbs et al., 2012; National Science Board, 2014; UNESCO, 2010; U.S. Congress Joint Economic Committee, 2012).

Experts in science education call for students to be more "scientifically literate" and gain experience with the tools and practices of science.

- Reports and guidance from major global institutions stress that this includes not only knowledge about the facts, theories, and concepts of science, but also an understanding about the practices of science (ISTE, 2007a, 2007b; National Research Council, 2012; OECD, 2007, 2014).
- PASCO's sensor-based investigations provide extensive opportunities for students to develop scientific literacy and familiarity with the practices of science through hands-on experiences using tools similar to those used by scientists and engineers. The availability of high-quality student equipment at low cost helps stretch precious science education resources further.

Use of technology tools for data collection, analysis, and visualization as part of hands-on, inquiry-based science instruction has been shown to deepen students' understanding of science concepts.

- Research confirms the positive impact of inquiry-based instruction on student understanding of science (Bredderman, 1983; Furtak et al., 2012; Minner, Levy, & Century, 2010; Schroeder, Scott, Tolson, Huang, & Lee, 2007; Shymansky, Hedges, & Woodworth, 1990; Weinstein, Boulanger, & Walberg, 1982).
- Research and expert opinion confirm the value of technology to support student data collection, analysis, and visualization, including sensors and probes (Linn & Hsi, 2000; Krajcik & Mun, 2014; Kulik, 2003; Rogers & Finlayson, 2004; Webb, 2008).
- Education experts specify that such technology is most effective in supporting student learning when it is used in an inquiry context (Krajcik & Mun, 2014; National Research Council, 2006; Webb, 2008).
- Technology use should support students in actively constructing meaning; be situated in an authentic, real-world context; provide cognitive tools; support specified learning goals; and scaffold student capabilities (Krajcik & Mun, 2014).

- PASCO provides technology tools that expand human capacity for data collection, analysis, and visualization, together with instructional resources to support use within an inquiry context, aligned with principles of positive instructional use of technology.
- PASCO technology also makes inquiry investigations more focused and time-efficient, with a corresponding benefit for teachers and students.

Involving students in hands-on, inquiry-based science can increase their motivation and interest in science.

- Research supports the motivational value of incorporating scientific inquiry activities and related engineering design activities into instruction (Barron et al., 1998; Crawford, 2014; Cunningham & Carlsen, 2014; Fraser, Giddings, & McRobbie, 1995; Kolodner et al., 2003; National Research Council, 2006; Scanlon, Jones, & Waycott, 2005; Webb, 2008; Wong & Fraser, 1995).
- Survey data show that many students find hands-on experiences using technology both motivating and memorable (Farris-Berg, 2008).
- Technology tools and instructional resources provided by PASCO help build students' interest in science through hands-on scientific inquiry and engineering design investigations.

Throughout the world, teachers are using PASCO sensor and data analysis technology to deepen student understanding of science concepts and practices while increasing student engagement and motivation in science.

- A physics and chemistry teacher in the Czech Republic has found that integrating scientific inquiry using PASCO tools helps university-bound students think critically and develop their research and problem-solving skills.
- A physics teacher in Australia has found that inquiry-based instruction using PASCO measurement tools helps students connect physics theory to practice and better visualize data—leading to improved student engagement and motivation. Teaching throughout his school has been revitalized as other teachers have adopted the same model of technology-supported inquiry.
- A secondary science instructional supervisor for a school district in the United States implemented a hands-on, inquiry-based science approach that incorporated PASCO technology, leading to increased motivation and creativity. During this time, student achievement on the state science exams has also improved, reflecting deeper understanding of scientific concepts and principles.

The Need for Qualified Science and Technology Professionals

There is a worldwide need to develop more qualified scientists, medical professionals, engineers, and technologists.

Economic and Social Benefits

Scientific expertise represents a key asset for national and world economies. In the words of the Organisation for Economic Co-operation and Development's report of the 2012 Programme for International Student Assessment (PISA), "Nurturing excellence in mathematics, reading or science, or in all three domains, is crucial for a country's development as these students will be in the vanguard of a competitive, knowledge-based global economy" (OECD, 2013, p. 9). According to a report from the McKinsey Global Institute, higher productivity among advanced economies in particular will "require rapid expansion in highly knowledge-intensive sectors of the economy, such as advanced manufacturing [and] health care" (Dobbs et al., 2012, p. 9).

The United States provides a case in point. A 2012 report to the U.S. Congress's Joint Economic Committee on STEM (science, technology, engineering, and math) education cited evidence that "half or more of economic growth in the United States over the past fifty years is attributable to improved productivity resulting from innovation," particularly with respect to computer, information, and biomedical technologies (U.S. Congress Joint Economic Committee, 2012, p. 1). More specifically:

> Technological innovation improves the competitive position of U.S. industries, drives export growth, and supports high-quality jobs. Additionally, demand for STEM-capable workers has increased even in traditionally non-STEM fields due to the diffusion of technology across industries and occupations. (U.S. Congress Joint Economic Committee, 2012, p. 1)

Professionals with knowledge in science and technology are needed not only to boost economic performance, but also to help solve the problems of tomorrow. For example, a 2010 UNESCO report on engineering worldwide identified a wide range of challenges for the future that require engineering expertise to solve, ranging from those related to "exploding urbanization . . . to the mounting concerns about availability of critical resources, the consequences of climate change and increasing natural and man-made disasters"—all of which "[make] ever-greater demands on engineering" (UNESCO, 2010, p. 43).

Benefits to Individuals

Scientific, mathematical, and technical expertise translates into benefits for students and future workers—contributing both to a country's overall social and economic health and to the satisfaction of its citizens: an important goal of many countries.

> Unemployment rates [in France] for holders of degrees in the humanities are five times as high as for graduates in engineering or health care. In the United States the average STEM major earns $500,000 more (in discounted lifetime earnings) than the average non-STEM major. This premium holds even when the STEM graduate is employed in non-STEM occupations. (Dobbs et al., 2012, p. 48)

High ongoing demand for STEM professionals makes such jobs particularly desirable. According to the U.S. National Science Board:

> During the 2007–09 economic downturn, S&E [science and engineering] employment remained more resilient in the United States than overall employment. Policymakers with otherwise divergent perspectives agree that jobs involving S&E are good for workers and good for the economy as a whole. These jobs pay more, even when compared to jobs requiring similar levels of education and comparably specialized skills. Although S&E workers are not totally exempt from joblessness, workers with S&E training or in S&E occupations are less often exposed to periods of unemployment. (National Science Board, 2014, p. 3-61)

In summary, possession of “the knowledge and skills needed to work effectively in jobs requiring STEM competencies” can lead to improvements in quality of life, working conditions, and wages for individual workers, with resulting value for countries and economies (U.S. Congress Joint Economic Committee, 2012, p. 1).

Meeting the Growing Need

As the demand grows for qualified workers in STEM-related jobs, there is widespread concern over whether supply can keep pace with demand.

Looking ahead to 2030, the McKinsey Global Institute report projects a worldwide shortage of high-skills workers, and particularly those with a STEM focus (Dobbs et al., 2012). The report projects further that such shortages could be avoided only by “doubling the growth rate in tertiary education attainment (while also raising the share of graduates in science, engineering, and other technical fields)” (Dobbs et al., 2012, p. 3).

Past years have seen global expansion in both knowledge- and technology-intensive industries (i.e., “high-technology . . . manufacturing [e.g., aircraft and spacecraft; pharmaceuticals] and knowledge-intensive . . . services [e.g., commercial business, financial, and communication services]”) and in the number of workers engaged in research (National Science Board, 2014, pp. O-3, 3-6).

Within developing economies, a shortage of qualified STEM professionals is already a limiting factor. For example, UNESCO found that “the lack of qualified engineers and technicians is currently reported to be one of the principal obstacles to economic growth encountered by innovative firms in many industrialized and industrializing countries” (2010, p. 71). Similarly,

> According to a report from the World Health Organization (WHO), around 95 per cent of medical technology in developing countries is imported and 50 per cent of the equipment is not in use. [A major reason] for this [is] lack of maintenance due to the lack of suitable training on the use of the equipment. . . . Repair facilities and spare parts are often unavailable, and the equipment has to be returned to the manufacturer, or specialized technicians have to be brought in at great cost. (UNESCO, 2010, pp. 133-134)

Concerns about the future supply of STEM professionals are not confined to less-developed economies. For example, in the United States,

> The demand for STEM-skilled workers is expected to continue to increase . . . as both the number and proportion of STEM jobs are projected to grow. New Bureau of Labor Statistics data show that employment in STEM occupations is expected to expand faster than employment in non-STEM occupations from 2010 to 2020. (U.S. Congress Joint Economic Committee, 2012, p. 2)

However, the U.S. educational system is not currently providing enough qualified workers to meet these needs:

> Despite the clear demand for STEM talent by domestic employers, the U.S. is failing to produce an ample supply of workers to meet the growing needs of both STEM and non-STEM employers. The existing STEM pipeline leaves too many students without access to quality STEM education, and without the interest and ability to obtain a degree or work in STEM. Current statistics on STEM education in the U.S. highlight the challenge facing educators and policymakers, making it clear that the United States must do more to build a strong STEM workforce if it is to remain competitive in the global economy. (U.S. Congress Joint Economic Committee, 2012, pp. 3-4)

For industrialized nations such as the United States, one solution has been to recruit qualified workers from other countries (National Science Board, 2014, p. 3-51). At best, however, this represents a relocation of valuable human resources—in many cases, away from areas of the world that are most critically in need of those resources. There is also concern that in the future, larger numbers of qualified graduates may choose to return to their home countries (U.S. Congress Joint Economic Committee, 2012, p. 4).

In short, the potential future—and in some cases, present—shortage of qualified science and technology professionals is a problem that educational systems around the world cannot afford to ignore.

The Need for Scientific Literacy and Hands-on Experience

What the Research Says

Experts in science education call for students to be more scientifically literate and gain experience with the tools and practices of science.

In addition to the need for science and technology professionals, a basic understanding of scientific concepts, processes, and ways of thinking is critical for all students in order to succeed in the world of today—and tomorrow. A report on the results of the international PISA 2012 science assessment explains, "An understanding of science and technology is central to a young person's preparedness for life in modern society" (OECD, 2014, p. 216). In order to address the economic, social, environmental, and technological problems of tomorrow, countries must ensure that their citizens possess this vital understanding.

Scientific literacy consists not only of knowledge about the facts, theories, and concepts of science, but also of understanding about the practices of science, including

> an individual's scientific knowledge, and use of that knowledge, to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues; understanding of the characteristic features of science as a form of human knowledge and enquiry; awareness of how science and technology shape our material, intellectual and cultural environments; and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen. (OECD, 2014, p. 216, citing OECD, 2007)

The International Society for Technology in Education (ISTE) 2007 *National Educational Technology Standards (NETS)* for students describe both ways that students should be able to use technology and instructional contexts in which it should be used. Three NETS standards are particularly relevant:

- "<u>Communication and collaboration</u>: Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others. . . .
- "<u>Research and information fluency</u>: Students apply digital tools to gather, evaluate, and use information. . . .
- "<u>Critical thinking, problem solving, and decision making</u>: Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources." (ISTE, 2007a).

Selected examples of tasks students at various age/grade levels might carry out in support of these standards are quoted in the table below (ISTE, 2007b):

Age/Grade Range	Sample Activities from ISTE Profiles
Ages 8-11 (U.S. grades 3-5)	• Select and apply digital tools to collect, organize, and analyze data to evaluate theories or test hypotheses. • Conduct science experiments using digital instruments and measurement devices.

Age/Grade Range	Sample Activities from ISTE Profiles
Ages 11-14 (U.S. grades 6-8)	• Gather data, examine patterns, and apply information for decision making using digital tools and resources. • Employ data-collection technology such as probes, handheld devices, and geographic mapping systems to gather, view, analyze, and report results for content-related problems. • Select and use the appropriate tools and digital resources to accomplish a variety of tasks and to solve problems.
Ages 1418 (U.S. grades 9-12)	• Select digital tools or resources to use for a real-world task and justify the selection based on their efficiency and effectiveness.

In the United States, the *Framework for K-12 Science Education* recommends that K-12 science education be built around "three major dimensions":

- "Scientific and engineering practices
- "Crosscutting concepts that unify the study of science and engineering through their common application across fields
- "Core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science" (National Research Council, 2012, p. 2).

The *Framework* describes the importance of practices as part of scientific knowledge as follows:

> Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. . . . Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.
>
> The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study. . . . Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering. (pp. 42-43)

Specific scientific and engineering practices identified in the *Framework* include:

"1. Asking questions (for science) and defining problems (for engineering)

"2. Developing and using models

"3. Planning and carrying out investigations

"4. Analyzing and interpreting data

"5. Using mathematics and computational thinking

"6. Constructing explanations (for science) and designing solutions (for engineering)

"7. Engaging in argument from evidence
"8. Obtaining, evaluating, and communicating information" (p. 3)

For science, all of these practices are integrated into the practice of inquiry (pp. 44-46).

How PASCO Helps Students Acquire Scientific Literacy and Hands-on Experience

PASCO's sensor-based investigations provide extensive opportunities for students to develop scientific literacy, familiarity with the practices of science, and scientific ways of thinking through hands-on experiences using tools similar to those used by scientists and engineers. Investigations are designed to help students explore a core science topic by designing and conducting their own investigation, utilizing a process of scientific inquiry.

Increased Access to the Tools of Science

One of the ways PASCO helps students develop scientific literacy and acquire hands-on experience is by providing access to high-quality student equipment with capabilities similar to those of professional scientific equipment at a fraction of the cost, so that precious resources for science classrooms can stretch further. For example:

- PASCO's colorimeters and spectrometers allow study of high-quality data without the prohibitive expense of a classroom set of industry equipment.
- PASCO's multi-measure sensors in areas such as weather, advanced chemistry, and water quality allow collection of multiple, simultaneous measurements in a single sensor. This not only helps keep costs down, but also helps conserve instructional time by reducing the time it takes to set up sensors and collect the data.

Support for Students in Developing Science Skills

For example, PASCO's physics laboratory activities support the following three levels:

- <u>Structured inquiry</u>: This format provides the highest level of support, with thorough background information and formal, step-by-step guidance for setting up the investigation and collecting data, and a pre-defined data analysis procedure with prescribed displays and manipulation techniques.
- <u>Guided inquiry</u>: This format provides the same background information as the structured format, but does not include step-by-step guidance for setting up the investigation and collecting data. Rather, it asks questions designed to invoke inquiry and guide students to design their own procedures. Students also decide how they will present data to properly fulfill the lab objectives and address the problem statement.
- <u>Open inquiry</u>: This format provides a problem statement and equipment list, but otherwise prompts students to design and execute their procedures with little or no guidance. This format does not provide background information.

More specifically, within the PASCO investigations, students perform some or all of the following practices:

- Formulate questions for open-ended inquiry investigations
- Make decisions about how to carry out the investigation
- Collect data
- Analyze, interpret, and evaluate data, including use of mathematics and scientific reasoning
- Collaborate as part of the investigation (in particular using the data-sharing feature in SPARKvue)
- Draw conclusions and solve problems based on data, analysis, and reasoning
- Communicate findings and conclusions

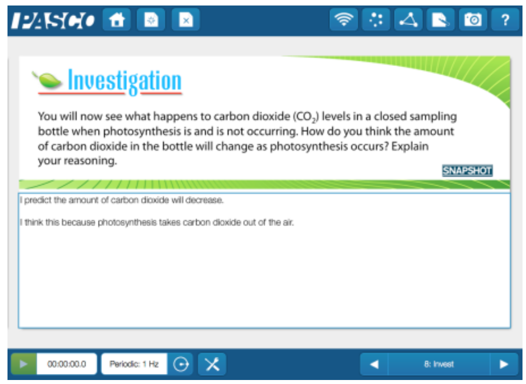
Sample Sensor-Based Investigations

The sample PASCO sensor-based investigations described below demonstrate how PASCO helps students acquire scientific literacy and hands-on experience with the tools and practices of science. These activities are more than "confirmation" labs, but rather require that students think critically, apply problem solving skills, make decisions in planning and designing an investigation, and analyze data.

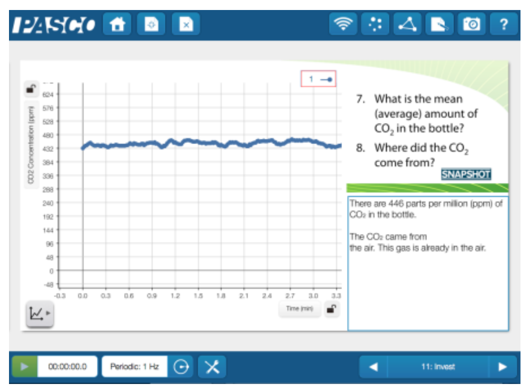
Example 1: Photosynthesis and Respiration (ages 10-14)

In the first part of the *Energy Grabber* SPARKlab, students see what happens to carbon dioxide (CO_2) levels in a closed sampling bottle when photosynthesis is and is not occurring. Later in the investigation, students are given the opportunity to explore another research question. This investigation provides opportunities for students to practice important science process skills, including making predictions and hypothesizing, hands-on data collection, interpreting data, communicating results, and planning independent investigations, as shown below.

1. Before conducting the investigation, students predict what will happen to the CO_2 level in the closed bottle when photosynthesis occurs and explain their reasoning. In this case, the student predicted that the "amount of carbon dioxide will decrease… because photosynthesis takes carbon dioxide out of the air."



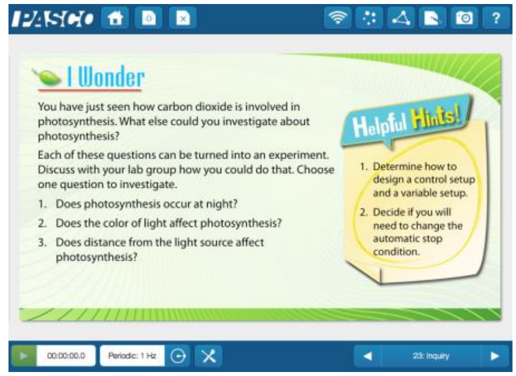
2. Students are guided in their setup of the experiment and collect CO_2 data from a tightly sealed bottle that has been under a light source for 2 minutes. They collect data for 5 minutes. In this case, students interpret the graph and conclude that there are "446 parts per million (ppm) of CO_2 in the bottle. The CO_2 came from the air." This represents the control condition, which students will compare with data they collect in the next procedure.



3. Students add spinach leaves to the bottle and repeat the experiment. Students interpret the graph and conclude that under this condition, "the CO2 level in the bottle decreased 113 ppm."

   Students are asked to compare the prediction with the results and suggest reasons for differences. Analysis and synthesis questions follow to help them think about the cause of the change in the CO2 level, the likely effect on the oxygen level, and the role of photosynthesis in the food chain.

4. After completing their initial investigation on photosynthesis, students are given the opportunity to investigate the topic further with questions such as: *Does photosynthesis occur at night? Does the color of light affect photosynthesis? Does the distance from the light source affect photosynthesis?* Depending on students' abilities, teachers could also choose to have their students generate their own questions for the investigation. In their lab groups, students select a question to investigate, discuss how to turn the question into an experiment (including control and variable setups), and conduct the investigation.



5. Throughout the SPARKlab investigation, teachers assign students to keep a lab journal by taking a snapshot of any screen, including data displays and students' responses to questions. Students annotate snapshots with any other ideas they may have.

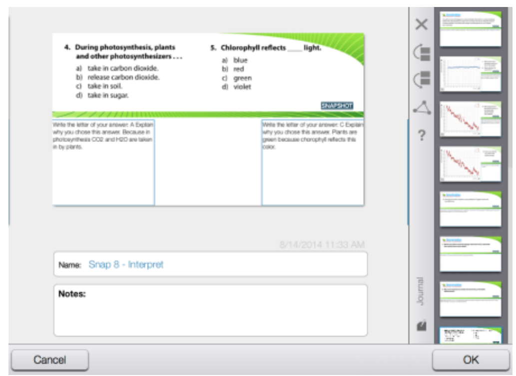


Figure 1: ***Energy Grabber*** **SPARKlab pages in SPARKvue App**

Example 2: Simple Pendulum (High School Advanced Physics)

Simple Pendulum, an investigation presented in the Advanced Physics Guide, is an example of a lab that allows the teacher to choose the format, given the knowledge and problem-solving abilities of the student, as described above under Support for Students in Developing Science Skills. In conducting this investigation, students answer the driving question, "*What variables affect the period of a pendulum? Determine what physical properties of a simple pendulum affect the period.*" At the end, they present their results to the class, and the teacher facilitates discussion of the findings.

As part of this investigation, students learn science content and processes, utilize technology, and practice problem-solving skills, including:

- Collaborating in groups modeled after those used by working scientists
- Formulating and/or refining questions to investigate
- Planning and carrying out investigations (guided and open inquiry formats)
- Collecting, analyzing, and interpreting data and applying mathematics/statistics
- Drawing conclusions and solving problems based on data analysis
- Communicating processes, findings, and conclusions to analysis questions at the end of an investigation
- Engaging in argument from evidence (explain and debate disparity in data)

Sample instructions, guiding questions, and top-level guidance for the three investigation formats are shown in the table below.

Structured Inquiry Sample subset of instructions	Guided Inquiry Supporting questions	Open Inquiry Top-level guidance
1. With your hand, pull the pendulum bob back, displacing it a horizontal distance of 3 cm from its equilibrium position. Use the meter stick to measure horizontal displacement. 2. Begin recording data, and then release the pendulum bob as it swings freely through the photogate. 3. Stop recording data when the data collection system has recorded 10 period measurements. 4. Use the tools on your data collection system to determine the average of the 10 period data points. Record this average value as well as the horizontal displacement into Table 1 in the Data Analysis section. 5. Repeat the data collection steps 3 more times, increasing the horizontal displacement by an additional 3 cm each trial. Record your average period and displacement values for each trial into Table 1.	1. How do you plan to construct your simple pendulum? What will the bob be made of, what will the pendulum arm be made of, and how will you anchor the pendulum arm? 2. What are 3 physical properties of your pendulum that can be changed that you believe will affect the period of the pendulum? 3. How do you plan to change each of these properties within your experiment? Explain the process for changing each. 4. How would you assemble the equipment from the materials provided in preparation for making measurements? Explain the important points regarding your setup, and explain how you plan to measure the period of the pendulum. 5. The experimental process can involve changing at least one variable while keeping others constant. Which variables will you change and which will be held constant?	1. It is your group's responsibility to design and conduct an experiment whose data will support your answer to the driving question. 2. After you have determined an experimental setup and procedure, write an outline of the equipment setup and procedure you will use to collect data, identifying the steps in sequence and the points at which each piece of equipment will be used.

A similar multi-tier model is used in high school advanced biology and chemistry.

Example 3: Biosphere Challenge (High School Biology STEM Module)

PASCO's project-based learning (PBL) STEM modules likewise assist students in developing specific science skills while learning science content. Each module focuses on all four components of STEM (science, technology, engineering, mathematics) and is guided by content standards; activity-based, inquiry-based, and problem-based learning; the expectation of a tangible product or process as an outcome; and formative and summative assessments. These modules incorporate both independent and collaborative work and rely on the engineering design process, including the steps of identifying the problem, identifying design constraints, researching design ideas, selecting the best solutions, building a prototype, and testing and evaluating.

For the *Biosphere Challenge* module, students explore photosynthesis, cellular respiration, and decomposition by measuring the carbon dioxide concentration in a closed environment and creating a mathematical model. They synthesize their data to design, construct, and test a balanced ecosystem that can sustain a macroinvertebrate or fish. More specifically, students

1. Independently design initial solutions
2. Revise these solutions based on the results of structured group activities

3. Analyze and evaluate approaches of the students in their group
4. Finalize a group design
5. Build a model or prototype for testing
6. Conduct the test
7. Review their design in light of test results and propose improvements, iterating within the engineering design process where appropriate
8. Present their results to the teacher and class

Skills students utilize in their investigation and construction of a biosphere include:

- Planning and carrying out investigations
- Graphical analysis and interpretation
- Dimensional analysis and unit conversion
- Creating mathematical models
- Measuring rate of CO_2 change with a carbon dioxide sensor
- Error analyses
- Collaborating in groups in ways that reflect real-world science investigations
- Communicating processes, findings, and conclusions
- Discussing differences across projects (methods, materials, data collection, data analysis) to get at the varying results

Technology-Supported Inquiry to Build Scientific Understanding

What the Research Says

Use of technology tools for data collection, analysis, and visualization as part of hands-on, inquiry-based science has been shown to deepen students' understanding of science concepts.

Value of Inquiry-Based Instruction

A substantial body of research confirms the positive impact of inquiry-based instruction on student understanding of science (Furtak et al., 2012, p. 301, citing earlier meta-analyses and research reviews).[1] For example, as part of a recent survey of studies about inquiry-based teaching (the Inquiry Synthesis Project), Minner et al. (2010)

> identified a subset of 42 comparative studies that contrasted inquiry-based teaching with other approaches. Of these studies, 55% found students in the condition with "higher inquiry saturation" to outperform students in the comparison group. . . . Overall, the authors argued that their synthesis indicates a "clear, positive trend in favor of inquiry-based teaching." (Furtak et al., 2012, p. 303, quoting Minner et al., 2010, pp. 483, 474)

Furtak et al.'s own meta-analysis found substantially higher science learning from inquiry-based instruction in primary and secondary classrooms, compared to other methods lacking inquiry characteristics—with a mean effect size of .50[2] over 37 studies from around the world published between 1996 and 2006 (Furtak et al., 2012, p. 315).

As part of their meta-analysis, Furtak and colleagues identified four "domains" of inquiry instruction: procedural, epistemic (i.e., understanding the nature of and acquisition of scientific knowledge), conceptual, and social. Each of these was further divided into subcategories. The studies were then categorized according to which inquiry domains were present in one condition but absent in the other condition. According to the researchers,

> The 3 studies that explicitly contrasted the epistemic domain of inquiry had the largest mean effect size on student learning [.75], followed by the 6 studies that contrasted the procedural, epistemic, and social domains [.72]. (p. 318)

These findings confirm the particular importance of the epistemic domain—including subcategories about the nature of science, drawing conclusions based on evidence, and generating and revising theories—as a component of effective inquiry instruction. The authors interpreted these findings as "suggest[ing] that engaging students in generating, developing, and justifying explanations as part of other science activities is an important element to helping students learn science" (p. 323).

Furtak et al. also codified studies based on the degree of guidance provided to students: as teacher-led traditional instruction, teacher-guided inquiry, or student-led inquiry (discovery learning). While the 6 studies that directly contrasted teacher-guided v. student-led inquiry were essentially the same in effect size (mean difference = .01), there was a substantial difference when each one was compared to

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[1] Specific sources cited include Bredderman, 1983; Minner, Levy, & Century, 2010; Schroeder, Scott, Tolson, Huang, & Lee, 2007; Shymansky, Hedges, & Woodworth, 1990; and Weinstein, Boulanger, & Walberg, 1982.
[2] Standard deviation = 0.56.

teacher-led traditional instruction: “the 10 studies that explicitly contrasted teacher-guided reform versus traditional conditions had a higher mean effect size [.65] than the 5 that contrasted student-led reform versus traditional [.25]” (p. 319). These findings suggest that some degree of teacher guidance is more likely than “pure” student-led discovery learning to result in improved student learning, compared to traditional instruction.

Value of Data Collection, Analysis, and Visualization Technology

Describing the value of technology to help students learn science, Krajcik and Mun (2014) identified six ways technology can support the “important learning goal” of “accessing and collecting a range of scientific data and information” by supporting students as they

- “Use visualization, interactive, and data analysis tools similar to those used by scientists,
- “Collaborate and share . . . information across remote sites,
- “Plan, build, and test models,
- “Develop multimedia documents that illustrate student understanding . . .
- “Access information and data when needed, and
- “Use remote tools to collect and analyze data” (Krajcik & Mun, 2014, p. 338)

Describing the value of situated learning, they noted that “various probes can help students conduct, collect, and analyze data, and students can use portable technologies to record information, including digital images and movies, in the field” (p. 340).

Along similar lines, a review of research from the *International Handbook of Information Technology in Primary and Secondary Education* identified data logging (also referred to as microcomputer-based laboratories [MBL]) as one of three types of instructional technology use that “have been shown to promote science learning” in schools (Webb, 2008, p. 134).[3] According to Webb,

> Research . . . over many years has produced varying results (Kulik, 2003). . . . Linn and Hsi (2000) found that pupils are much better at interpreting the findings of their experiments when they use real-time data collection than when they use conventional techniques for graphing their data, and that this greater understanding is carried over to topics where they have not collected the data. Russell et al. (2004) found that interactions with MBL and associated student–student interactions were supporting deep learning. (Webb, 2008, pp. 137-138)

Webb also described technology-related benefits stemming from “greater opportunities for meaningful interaction with teachers” and gave as an example, “students work[ing] in groups using data-loggers to record experimental results, [which] freed up the teachers to circulate and stimulate discussion and thinking about the results” (Webb, 2008, citing Rogers & Finlayson, 2004).

Krajcik and Mun (2014) explained the benefits of this technology as follows:

> The use of probes in the classroom . . . allows learners to engage with several science practices critical to supporting students in learning science. The most salient practices include designing and carrying out investigations, analyzing and interpreting data, and computational and mathematical

[3] The terms *data logging*, *probeware*, and *microcomputer-based laboratories (MBL)* all refer to student use of probes, sensors, and other technology tools to collect or measure data, together with software tools that allow for data analysis and (often) visualization of findings.

> thinking. However, the use of probes also supports students in asking and refining questions and engaging in argumentation from evidence. (p. 344)

Use of Technology to Support Inquiry

Education experts specify further that technology—including technology tools for data collection, analysis, and visualization—is most effective in supporting student learning when it is used in an inquiry context. Krajcik and Mun (2014) report:

> Recent educational approaches emphasize the use of technology in environments in which learners engage in extended inquiry and develop knowledge and skills in the context of investigating complex and meaningful problems. . . . Learning environments, including those that incorporate learning technologies, should engage learners in challenging and open-ended problems to provide students with opportunities to grapple with ideas and make connections. In such environments, students develop an integrated understanding of scientific core ideas by applying and using them to explain phenomena, solve problems, and make decisions. (pp. 338-339)

Along similar lines, *America's Lab Report* compared "typical" laboratory experiences (i.e., lab practicals) that are "disconnected from the flow of classroom science lessons" with laboratory experiences that are integrated with "other types of science learning activities, including lectures, reading, and discussion" and in which "students are engaged in framing research questions, making observations, designing and executing experiments, gathering and analyzing data, and constructing scientific arguments and explanations" (National Research Council, 2006, p. 4). The report found that students learned more from integrated laboratory experiences with respect to both mastery of subject matter and scientific reasoning (p. 100). This agrees with Webb's (2008) conclusion that technology "can . . . play a larger role when its use is fully integrated into the curriculum" (p. 143).

Principles of Effective Technology Use

According to Krajcik and Mun (2014), in order to effectively support student learning, technology should be used in ways that align to major learning principles. Specifically, technology use should:

- Support the student in "actively construct[ing] meaning based on his or her experiences and interactions in the world" (p. 339)
- Be "situated in an authentic, real-world context" (p. 340)
- Provide cognitive tools to help "amplify and expand what students can do in constructing knowledge," e.g., through software that "allow[s] learners to visualize complex data sets" (p. 342)
- Support specified learning goals (p. 342)
- Scaffold student capabilities by "support[ing] and assist[ing] learners in accomplishing a challenging task . . . that would otherwise be unattainable" (p. 342)

How PASCO Builds Scientific Understanding Through Technology-Supported Inquiry

While technology does not create scientific understanding, appropriate technology represents a key tool for promoting inquiry investigations using quantitative results that can result in meaningful learning for students.

PASCO combines instructional resources, professional development, and technology to support successful inquiry learning. More specifically:

- PASCO equipment expands human capacity in order to enable a wider variety of potential investigations. For example:
  - High-sensitivity light sensors can measure the flickering of fluorescent lights, which is too fast for human eyes to see. Similarly, force sensors capture forces in a collision in fractions of a second that can't be seen without technology.
  - Spectrometers allow for easy analysis of plant pigments and absorbance spectra, giving students firsthand experience with data they usually see only in a textbook.
  - Motion sensors quickly and continuously measure position, velocity, and acceleration. This allows for real-time data collection, visualization, and instant analysis that students could not do with traditional equipment.
  - The EKG sensor makes it possible for a student to measure the electrical activity of his or her heart and identify specific waves.
- Activity outlines provided by PASCO support the critical epistemic domain of inquiry learning, in which students generate, develop, and justify explanations.
- High-quality technology tools from PASCO facilitate quick, accurate data collection—freeing teachers and students to spend more time on activities that promote deeper thinking, including those identified by Furtak et al. (2012) as relating to the epistemic domain. For example:
  - pH sensors can be used to move students from taking a single traditional titration to quickly generating multiple titration curves. As a result, students spend more time on curve analysis and interpretation.
  - Utilizing carbon dioxide gas sensors to investigate photosynthesis enables students to directly measure a change in concentration of one of the reactants of the process. The sensor accomplishes in minutes what would take a 24-hour period using traditional methods.
- The PASCO teacher materials and professional development provide guidance to teachers on ways to effectively carry out inquiry investigations, including integrating inquiry with the regular course of instruction.
- PASCO equipment is specifically designed for instructional use—providing more effective support for inquiry investigations by helping students focus on what they are supposed to learn. For example, traditional cell respiration labs are typically complex and inaccurate. In contrast, a PASCO respiration lab activity is built to facilitate student understanding. Setup for a carbon dioxide or oxygen gas sensor is simple, and accurate data is collected in minutes with minimal frustration.
- Instructional materials and professional development for teachers using PASCO materials encourage teachers to provide guidance and set learning goals, while at the same time directing students to make decisions and take ownership of their inquiries.
- Activities are designed to help students construct meaning experientially and develop a firmer understanding of key scientific concepts.

- Activities incorporate cognitive tools to help students make sense of what they are learning. For example:
  - As noted in the Introduction, SPARKvue offers a full suite of options to display and analyze live sensor data, providing tools for students to visualize data in multiple ways.
  - Screen snapshots provide additional tools for students to visually compare predictions with results, compare results after one or more variables have changed, and show changes over time.
- Instruction resources, features, and professional development provide suggestions on ways to scaffold student capabilities. For example:
  - As shown in the sample sensor-based investigations described earlier in this paper, multiple levels of guidance and support for students are provided for specific investigations. Teachers can select the level of support that best matches students' skills and experiences so that they can accomplish challenging tasks.
  - Teachers can adjust display options and sensor settings within the SPARKvue software to match the needs of their students.
  - Professional development workshops guide teachers to begin with more highly structured activities, then help students move over time to open-ended investigations where students take more responsibility for planning their own activities—informed by teachers' assessments of students' readiness to complete learner-led investigations.

Technology-Supported Inquiry to Build Interest in Science

What the Research Says

Involving students in hands-on, inquiry-based science can increase their motivation and interest in science.

Research on Instruction

Research supports the value of inquiry-based science instruction for its potential to motivate students and build their interest in science. According to a 2014 review of inquiry practices in primary and secondary science classrooms, “There is ample evidence that classroom-based inquiry science can be beneficial to . . . developing positive attitudes toward life-long science learning” (Crawford, 2014, p. 537).

More specifically, a 2006 report on high school science laboratory experiences in the United States—including experiences that use technology tools for data collection, analysis, and visualization—found evidence that such experiences can increase students’ interest in science, particularly when integrated with other science learning experiences and when “students are engaged in framing research questions, making observations, designing and executing experiments, gathering and analyzing data, and constructing scientific arguments and explanations” (National Research Council, 2006, p. 4).

This report indicated that “current designs of science curricula that integrate laboratory experiences into ongoing classroom instruction have proven effective in enhancing students’ . . . interest in science” (National Research Council, 2006, pp. 25-26). The authors concluded, “Students who participate in these units show greater interest in and more positive attitudes toward science” (p. 97). Research further indicates that

- “Positive student attitudes are particularly strongly associated with cohesiveness (the extent to which students know, help, and are supportive of one another) and integration (the extent to which laboratory activities are integrated with nonlaboratory and theory classes)” (p. 97, citing Fraser, Giddings, & McRobbie, 1995; Wong & Fraser, 1995).
- “Teaching strategies that encourage students to articulate their hypotheses about phenomena prior to experimentation and to then reflect on their ideas after experimentation are demonstrably more successful at supporting student attainment of the [goal] of . . . increasing interest in science and science learning” (p. 102).

A synthesis of research on precollege engineering education and its relationship to science learning described “evidence that by emphasizing personal, real-world connections and constructing a need to know for related science, engineering design activities can enhance student motivation to learn science” (Cunningham & Carlsen, 2014, p. 747, citing Barron et al., 1998; Kolodner et al., 2003; see also p. 754). Such activities typically involve a design process that incorporates inquiry-related practices (p. 749), and often involve hands-on student use of technology. Elements of engineering design activities with particular potential to motivate students include

- “Giving students authority to solve problems” (p. 750)
- Exploration of “diverse solutions” in a context of multiple competing values (p. 750)

- “The practical context of these problems” (p. 751)
- “An emphasis on the social value of the object of student learning” (p. 750)
- “Enhancing students’ sense of their own competence and agency” (p. 754)

Additionally, research has found that mobile technology has specific potential to motivate students. A summary of research related to use of instructional technology in science education reported, “Evaluations by learners and teachers suggested that use of hand-held devices together with wireless networking enhanced learners’ experiences and their motivation for learning science in a range of settings, including fieldwork and museum visits” (Webb, 2008, p. 140, citing Scanlon, Jones, & Waycott, 2005).

Student Opinions

Information from a survey of student opinions suggests that hands-on experiences using technology are both motivating and memorable for many students. The 2007 Project Tomorrow Speak Up Survey found that primary and secondary education students tended to value both hands-on science activities and use of technology in STEM subjects.

- 38% of middle school (i.e., ages 11-14) and high school students (i.e., ages 14-18) surveyed “indicated that their interest in STEM careers could be improved if they had opportunities to ‘use advanced technology, laboratory devices, or professional tools’” (Farris-Berg, 2008, p. 15). Among high school students who were “maybe” interested in STEM careers, 44% were motivated by “tech tools,” rising to 66% of those who were “yes interested” in STEM careers (p. 14).
- 36% of middle school and high school students surveyed “reported that hands-on learning opportunities would increase their interest in pursuing a STEM career. Among high school students, this was the most important strategy. Additionally, more than 30% of students said their interest would increase with classroom instruction that ties academic material to real world problems” (Farris-Berg, 2008, p. 16). Among high school students who were “maybe” interested in STEM careers, 48% were motivated by “hands on activities,” rising to 66% of those who were “yes interested” in STEM careers (p. 14).
- Asked to describe “an especially interesting or favorite learning experience in science or math,” a “large portion” of primary and secondary students who had experienced “hands-on, tangible activities and group-oriented learning methods in STEM subjects” found them to be “the most interesting” (p. 8). Middle school and high school students also “frequently mentioned that their most interesting learning experiences in science and math courses involved using interactive and advanced technology tools and engaging in activities with real-world relevance” (p. 10).

How PASCO Builds Interest in Science Through Technology-Supported Inquiry

Technology tools and instructional resources provided by PASCO can help build students’ interest in science in a variety of ways.

- Students experience hands-on learning using educational software, laboratory devices designed for educational purposes, and tools similar to those used by professional scientists.
- Within select instructional activities provided by PASCO for using technology tools, students are actively involved in “framing research questions, making observations, designing and executing experiments, gathering and analyzing data, and constructing scientific arguments and explanations”

(National Research Council, 2006, p. 4). Students are directed to articulate their hypotheses prior to experimentation and to then reflect on their ideas after experimentation.

- Guidance is provided within the PASCO teacher materials and professional development on ways to integrate inquiry activities with the regular course of instruction.
- Activities designed by PASCO encourage student cohesiveness through guided collaboration and group work.
- Activities in PASCO STEM modules typically give students authority to solve problems that have diverse possible solutions and incorporate a practical context, social value, and opportunities for students to develop a sense of competence and agency—factors of engineering design activities identified as motivating by Cunningham and Carlsen (2014).

  In addition to the STEM modules, many of PASCO's sensor-based investigations for primary and secondary students incorporate activities in which they respond to challenges by applying engineering concepts and practices.
- Using PASCO's mobile technology tools, students access science anytime and anywhere while doing science both inside a traditional classroom or lab and out in the field.
- Activities provided by PASCO incorporate connections to real-world problems. For example:
  - The *Biosphere Challenge* activity involves students in addressing the kinds of challenges that might be expected in determining habitats for survival of a species and then designing, building and testing those habitats.
  - Similarly, the classic *Egg Drop Challenge* takes middle school students back to 1996 and the Mars Pathfinder mission, which required designing mechanisms to prevent the Pathfinder from being crushed during its high-impact landing on the surface of Mars. The challenge facing students is to design and construct a device that will protect a fresh, raw egg from cracking when it falls to the ground from a height of 6 meters. To prepare for the task, students explore concepts related to force and motion (e.g., velocity, acceleration, force and collisions, air drag), then design, construct, and test a "space module" for a fragile raw egg.

Inquiry-Based Science with Technology Tools: Three Examples Across the Globe

Throughout the world, teachers are effectively implementing inquiry-based science instruction that takes advantage of technology tools for collecting, analyzing, and visualizing data. Such teachers find that this approach to science education helps students deepen their understanding of science concepts and practices while also increasing student engagement and motivation in science.

In this section of the paper, three educators from the Czech Republic, Australia, and the United States share their experiences integrating PASCO sensor and data analysis technology into inquiry-based scientific explorations of real-world issues and questions.

Shifting Secondary Science Instruction in the Czech Republic

After teaching for ten years, physics and chemistry teacher Patrik Koci has come to believe that there are two main benefits to integrating the scientific inquiry process into science courses. It helps his university-bound students think critically about any problem they might encounter. It also develops students' research skills to measure and analyze data to determine a solution to a problem.

To support the inquiry process, he has expanded implementation of lab experiments using PASCO tools and students' presentation videos. The school purchased the PASCO tools with the aim of teaching students how to collaboratively analyze data in chemical experiments. Students are then guided to synthesize their findings and present the information to their classmates. Many of the experiments involve concepts of pollution, carbon dioxide, chemical reactions, motion, and pressure.

Each spring, after learning about how fertilizers and waste materials contaminate water and soil, Koci's students go out locally to measure, with the help of PASCO sensors, the increased number of ions in their local water and soil—specifically nitrates, chlorides, and ammonium ions. Students also take readings on conductivity, turbidity, and pH levels. Koci notes that generating their own data engages the students: "They are more motivated in doing the experiments, quantitative thinking, working with graphs, and generating outcomes when it comes from their own data."

Koci and his students also use the technology as a visualization tool. "We have a connected computer and multimedia table so we can show some things we are speaking about in a normal lesson . . . . We can show different types of motion; we are able to speak about pressure, pressure connected with water. We also can show everything that's connected with electric current and voltage, so it's visualization as well," according to Koci.

Koci summarizes the academic benefits of this approach as follows: "When we teach with PASCO tools, students are able to understand theory more easily. It leads them to quantitative language and helps them understand the issues in more detail."

Changing Instructional Model in Australia Deepens Student Learning While Promoting Student Engagement

Dan Belluz is a physics teacher in an all-boys K-12 grammar school (primary and secondary) in Victoria, Australia. With his year 11 physics students, he started the shift to an inquiry-based method of instruction. His overarching goal was to connect physics theory to practice with data that was accurate and meaningful. He was also looking for a better way for students to visualize data, leading to the adoption of PASCO measurement tools.

“It’s been almost impossible to measure the kinds of things that we needed to measure to show conservation of energy and conservation of momentum . . . . With the PASCO gear, using the tracks and the carts and the force sensors . . . we’ve been able to actually gather data that is meaningful, accurate, and shows or connects with the theory very well for the boys,” Belluz says.

Practical activities emphasize that the problems students are trying to solve have real-world applications. They learn that things around them can be measured and evaluated, such as respiration, heart rate, water quality, and electronic signals.

> In an in-class survey, the students reported greater feelings of confidence, engagement, and understanding of the task during activities involving use of science technology tools, compared to activities that did not include technology.

Belluz has observed dramatic changes in student visualization of physics phenomena. “There are things that I’m actually able to measure that we couldn’t measure in the past. An example of that is the photoelectric effect. Using the PASCO gear actually allows me to show the students for real what I’m talking about in the theory that I couldn’t show in the past. . . . graphs are generated automatically in front of [the students]; the results are instantaneous so they can see exactly what’s happening.”

Under the new model, Belluz typically talks for five minutes at the beginning of the period to give a conceptual overview of the activity, and then five minutes at the end to wind things up. During the rest of the class period, students are immersed in doing the experimental work themselves, with Belluz moving around the classroom from group to group addressing questions.

Because PASCO equipment is so easy to assemble, Belluz has found that the boys do not ask mechanical questions about how the equipment fits together, as in past lab experiments. Instead, they ask questions about the concepts and theories underlying the experiments they are conducting.

Belluz notes that the most obvious effect has been on student engagement and motivation. In a traditional lecture model, students fade in and out of attention; “but when they’re actually doing, they’re fully engaged and we found that we rarely had boys who were off task. . . . They were quite taken aback by the fact that they can actually do real scientific work, that is, use things that are similar to the …smart phones they’re using to actually analyze things that are happening in real time.”

For example, with “a motion sensor, the boys can use their bodies to demonstrate real time graphing; they can see real life being translated into analysis. This makes scientific inquiry more real to them, and they see that it does have application outside the textbook and classroom.”

Belluz conducted a comparison of teaching physics without technology to teaching with PASCO tools. Analysis of videotapes showed an increase in student engagement as well as deeper understanding of physics in the class using the technology tools. Additionally, in an in-class survey, the students reported greater feelings of confidence, engagement, and understanding of the task during activities involving use of science technology tools, compared to activities that did not include technology.

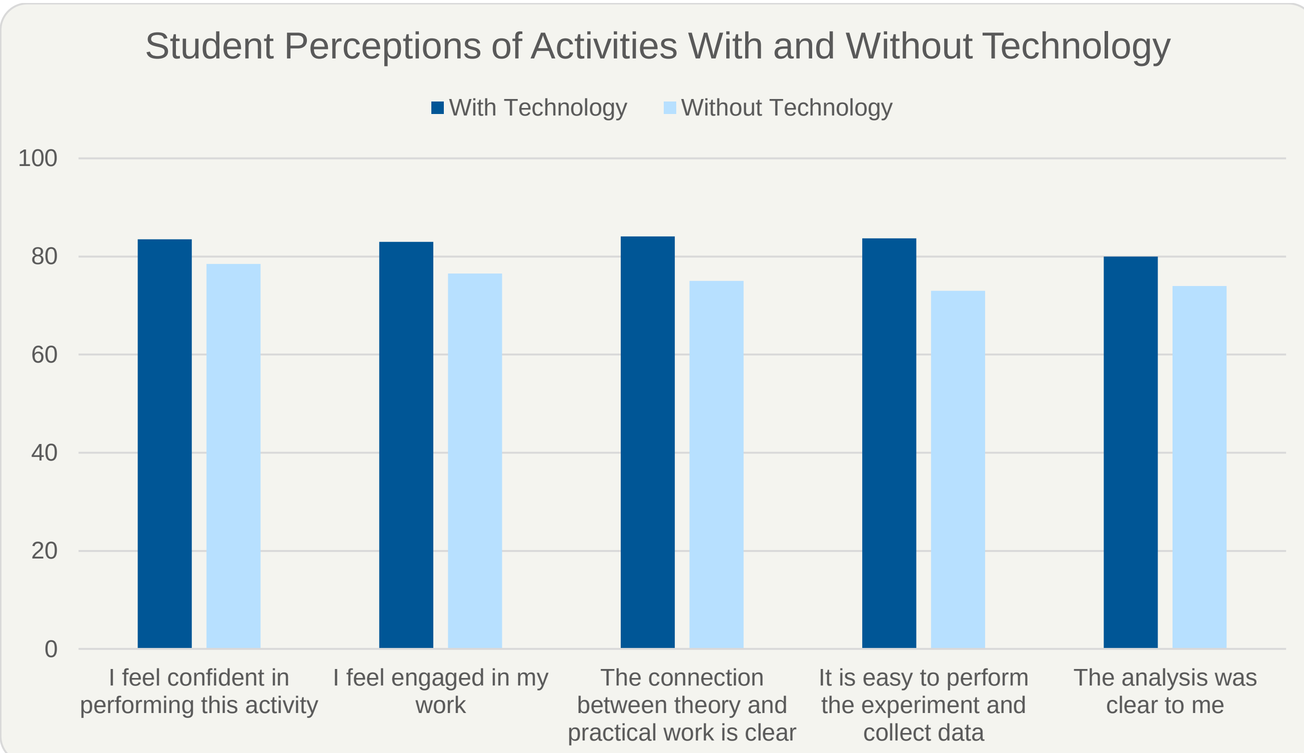

Figure 2. Student survey from Dan Belluz, Head of Science, Brighton Grammar, Victoria, Australia

As other teachers in his school have transitioned to student use of the technology tools, Belluz has found three distinct areas that are impacted by the shift in instruction:

- Student engagement has increased learning.
- There has been a positive impact on the teachers as the tools and process changed their pedagogy.
- The style of questioning has changed for both students and teachers and led to much deeper learning.

Belluz highlighted “the value that we have found in teachers’ engagement. Although almost accidental, it has allowed in some way a rebirth of interest because you can become quite stagnated in teaching the same way all the time. But the equipment allows us to look at new ways of teaching the same thing.”

Transitioning to Inquiry-Based Science Instruction in Newport News, Virginia, United States

> *"Students are more excited; they're more enthusiastic when they're doing these types of activities because they're taking ownership of their learning. It's their investigation. As a result, self-initiative, creativity, and innovation have increased."*
>
> Dewey Ray Jr., Newport News, VA

When Dewey Ray Jr. took the job of instructional supervisor for secondary science in Newport News, Virginia, in 2010, he had a big-picture vision of shifting to hands-on, inquiry-based science as a way to help students develop key college, career, and citizen readiness skills. He wanted students to have the skills and the science know-how to solve real-world problems. At the same time, the district wanted to revise the curriculum to include more inquiry, and the State of Virginia was bringing a new teacher evaluation online, in which administrators would assess teacher performance based on student growth. When Ray started, secondary science teaching relied heavily on PowerPoint presentations and students completing worksheets. However, Ray and the district leadership felt that they were not adequately preparing students for science careers with nearby major employers, such as NASA, United States military facilities, and shipbuilding companies.

The district redesigned its science labs, rewrote its science curriculum for grades 6–12, and moved to student pre- and post-assessments that are inquiry-based. Ray explained that each assessment is "a guided inquiry where we give the student a problem, but they have to go out and solve the problem. We do this at the beginning and end of a course, and we look to see how the students have progressed and how much they've gained during the course through a scientific investigation."

As an example, Ray cited a life science pre-assessment: "What is the effect of exercise on heart rate? So, the students have to be able to design an investigation around that testable question. Students can use the PASCO tools, but they must develop their [own] procedure and run their test. They collect data through graphing and charts, analyze their data, and then report, share, explain and defend their data."

According to Ray, one profound shift in the transition has been in student engagement and motivation. "Students are more excited; they're more enthusiastic when they're doing these types of activities because they're taking ownership of their learning. It's their investigation. They're the ones setting the procedure up, and most of the time, the students get excited and love to talk and share what they're doing in class. As a result," he states, "self-initiative, creativity, and innovation have increased."

Every 6th grade student in the district participates in a watershed field trip experience where they go out into the Chesapeake Bay, collect samples, and do water quality testing. Ray reported, "not only do the students use the PASCO tools for data collection, but they use the tools to help with visualization as well. The tools do the graphing, so students can have discussions about the graph and show trends."

"The students collect the data throughout the year. We get temperature readings, pH readings, and dissolved oxygen readings. When the students come back to class, they examine the reasons why there are differences in dissolved oxygen at different times of the year, or why the salinity of pH readings are different at a certain time of year. This is exactly what we want our students to be able to do, to get data and be able to justify it, analyze it, and talk about it."

Since the implementation of an inquiry-based approach to teaching science, Ray has seen an increase in student achievement. Data for the Virginia Standards of Learning (SOL) annual exams show an increase in assessment scores over five years. Biology scores have increased an average of 4%, chemistry 9%, and earth science an impressive 17%. Ray and the district leadership team believe these gains reflect a deeper understanding of scientific concepts and principles—that when students are seeing, perceiving, analyzing, reflecting, and constructing new knowledge for themselves by learning in a hands-on fashion, they develop strong problem-solving and critical thinking skills.

Although the transition to inquiry-based instruction has been largely successful, Ray cautions that they are not all the way there just yet. "We've done a lot of professional development over the last four years," he says. "We sent educators to PASCO headquarters for training, and we use them in the district as our PASCO experts. There have been many workshops, and we've worked with our content people to create labs for the curriculum using the sensors and SPARK Science [Learning System] units."

Ray plans to continue converting more science curriculum to inquiry process. "When I go into classrooms to observe and see the way students are attacking problems, it's very encouraging." He also notes that this shift requires a change in the teaching model where the teacher steps back from being the expert. Instead of telling the student what to do, the teachers' role is now to ask timely and meaningful facilitative questions to guide learning.

The district has recently hired a STEM instructional specialist to work with teachers and students on expanding scientific inquiry and to begin to expose students to potential STEM careers.

A Continuing Process

All three of these educators report that the shift to the inquiry learning model has been successful enough to warrant expansion to other grades and across science disciplines.
According to Dan Belluz from Australia, "the biology department now uses PASCO gear when they're studying respiration and have found it simple to set up and monitor extended periods of respiration of plants. They've also found it simple to use the CO_2 and oxygen sensors. The chemistry people have also really got on board, using all of the temperature and gas sensors. Now it's much more common for them to use sensors to monitor and gather data than just a pad of paper and pen with a traditional temperature gauge. We have also invited the junior school (grades K-6) to begin using the equipment."

Patrik Koci from the Czech Republic finds that inquiry-based learning gives students the experience and tools to approach any problem critically, gather and analyze the data, and determine an outcome or solution. Next year, the school will expand its program of experiments. They plan to add PASCO centers in a new mechanical laboratory that will allow more small groups of students to collaborate on experiments. The increase in equipment will allow more hands-on inquiry.

Dewey Ray Jr. from the United States notes that professional development for teachers and administrators is critical to managing the shift in pedagogy to inquiry and activity-based learning. Ongoing support of teachers is also important. "We have content team meetings, we meet with our lead teachers, we bring in a lot of student artifacts. We look at the students' work . . . and have discussions across schools, departments, and grade levels." He notes that an inquiry-based classroom looks different than a traditional classroom and everyone—from students to administrators—needs to know what that looks like and what to expect.

The three educators conclude that the emphasis on inquiry-based learning results in greater student engagement and motivation to “do” science. They believe that this will generate more student interest in STEM careers, but they predict that it will take some time.

Conclusion

In order to meet the needs of tomorrow, countries must prepare students for careers that will require extensive scientific expertise. By the time students start college, they need to have both the knowledge about science and the motivation to learn more that will help to launch them into a successful future.

Scientific inquiry experiences—with appropriate technology to extend student capabilities, provide experience with the tools and practices of science, and help motivate student learning—represent a key part of this preparation. PASCO provides a wealth of technology tools and instructional resources for data collection, analysis, and visualization that help make these kinds of inquiry investigations a reality for science classrooms around the world.

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