CENTER FOR TECHNOLOGY IN LEARNING

Nspired Learning in Science: What Research Says

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CONTENTS

Executive Summary

The history of efforts to improve the teaching of science, technology, engineering and math (STEM) curricula has included a number of change initiatives over the past 50 years at every level of education from elementary through post-secondary. Recently, the National Academy of Sciences (NAS) has published a framework for development of common core standards for science (Standards, 2011). Of particular importance for this discussion are five of the eight practices of science identified in the framework: **planning and carrying out investigations** (in particular, **data collection**); **analyzing and interpreting data; developing and using models; using mathematics, information and computer technology, and computational thinking; engaging in argument from evidence.**

These five practices frame this paper. Specifically, this report examines how features of TI's Nspired Learning system (including TI-Nspire and TI-Navigator), align with the need to build the practice of science into the curriculum, through the combination of hardware, software and research-based practices for learning and instruction.

First, we will examine the goals of the science curricula as defined by NAS, and discuss the roles technology can play. Then, we will review research on these five classes of learning activities pointing out ways in which Nspired Learning's capabilities could be particularly important to teaching of the practices of science.

Data Gathering through Probeware. (e.g. such as Vernier products and TI's Calculator-Based Laboratory products). Probeware facilitates gathering data in experiential settings, and provides students with graphic representations that enable them to connect data to underlying scientific concepts. A collection of research studies provide evidence that probeware and graphing products increase student comprehension of graphs and understanding of scientific concepts in both physics and biology. Given the popularity of probeware applications among science teachers and this evidence base, these applications are a strong example of how Nspired Learning technology could contribute to science classrooms.

Data Modeling, Simulation, Analysis and Interpretation. In science and engineering, research links graphical representations to "knowledge building" activities. Yet science teachers' graphing needs are not the same as those of mathematics teachers. In a science classroom, the process of constructing a graph is less important than its interpretation. Science teachers often use **color and animation** (capabilities of TI-Nspire CX) to illustrate patterns in complex data sets. For example, by using different colors on a weather map to represent different temperature zones, teachers can engage students in exploring patterns across data sets, setting the stage for investigating the conditions that cause severe storms, movements of weather fronts, and flooding. The data sets which are graphed can be generated by students in the classroom or the field, or they can be downloaded from internet resources and analyzed on TI-Nspire. TI-Nspire provides a wide range of capabilities which would support these activities.

In science and engineering, simulation is useful both for observing and making sense of phenomena in the "real world," and for visualizing and making sense of the otherwise abstract relationships among variables in modeling. The simulation capabilities of TI-Nspire could provide easy ways to place simple simulations in every student's hands.

Formative Assessment, Argumentation and Explanation. Research shows that the Nspired Learning classroom system can be used to implement **peer argumentation and explanation,** through a range of **formative assessment** and **collaboration** approaches which engage students in crafting assertions, recognizing misconceptions and building more satisfactory understandings of foundational scientific concepts. As part of this discussion, we will review Nspired Learning's formative assessment and collaboration facilities.

Finally, we will discuss **a commonly used best practice in teaching:** use of technology to offload unnecessary cognitive complexity during scientific inquiry.

Throughout the discussion, we discuss the affordances of **Documents** (.TNS and PublishView) in scaffolding scientific reasoning**.** Documents are important for several reasons. Science teachers often see little value in students' spending time to set up a complicated set of graphs, tables, and equations for data analysis. Using **TI-Nspire documents** could save time and increase student engagement in laboratory activities, while providing continuity between the lab and the classroom. As use of multiple representations is a key research-based practice in science, teachers may find TI-Nspire documents particularly helpful. Documents also can hold **reference materials**, such as a periodic table of the elements, lists of key laws and equations, and lists of conversions between units. Science teachers have provided examples of how TI-Nspire's symbolic algebra features can be used to simplify useful calculations in biology and chemistry, such as the calculation of molar weights of reagents. Documents also can efficiently contain **complex real-world data sets** and give students the data handling power to use them. Thus, it is no longer necessary to limit instruction to data sets which are artificially simplified and generated within the classroom.

When students have access to laptops or desktop computers, TI-Nspire **PublishView** embeds math objects and graphic and video objects dynamically in documents. These documents can efficiently scaffold a learning activity in the lab or the field, they can save time with setup of a class, and they can add additional power to learning resources of many kinds. PublishView is thus particularly important for support of argumentation and explanation constructed by students.

Taken together, these research-based uses of technology to support learning of the processes of science learning provide a field of opportunities for teachers to use the Nspired Learning platform to make a significant impact in science classrooms.

Introduction

This paper draws from two related lines of research on science education and how technology is best used in science learning and instruction. The first line of research is reflected in the contemporary effort to develop Common Core Standards for science in K-12 curricula. The second line of research is about uses of technology to address common challenges in teaching science.

Common Core Standards for Science. The framework for the Common Core Standards in Science, recently published by a committee of the National Academies (Standards, 2011), represents a synthesis of research on K-12 science and engineering curricula, teaching and assessment done over the past generation. It presents a three-dimensional framework, which defines the space of the curriculum (p.2-5):

1. Scientific and engineering practices
2. Crosscutting concepts – that is, those having applicability across science disciplines
3. Core ideas in the science disciplines and of the relationships among science, engineering, and technology.

While there are many challenges within this space associated with curriculum, teaching and assessment, we focus on four of the major challenges for improving science curricula:

- Building understanding and addressing student misconceptions about science (dimensions 2 and 3)
- Enabling students to learn the process of scientific inquiry (dimension 1)
- Providing adequate feedback to teachers and students to shape learning (all dimensions)
- Increasing student engagement in scientific argumentation (dimension 1)

The framework emphasizes that these dimensions need to be combined in a curriculum, so students experience the integration of scientific content and practices. Students need to engage in the full range of practices as a means to deepen understanding of science and science content. In the framework, the practices for science and engineering classrooms include (p.3-5):

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, information and computer technology, 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

Of particular importance for this discussion are five of these practices: **planning and carrying out investigations** (in particular, **data collection**); **analyzing and**

interpreting data; developing and using models; using mathematics, information and computer technology, and computational thinking; engaging in argument from evidence. When creating learning activities which apply these practices, we believe technology's most valuable use is in meeting the challenges of teaching and learning discussed below. Thus, following the lead of the current thinking on science curriculum standards, our argument for the best use of technology is built on the three dimensions, five of the processes of science, and four challenges of teaching them.

Common challenges in teaching science. Beginning in the post-Sputnik era, and especially since the cognitive science revolution of the 1980s and the publication of the seminal public education critique, "A Nation at Risk," (Education, 1983), American science teachers have increasingly designed creative and varied lessons for engaging their students in learning important scientific concepts and processes. A visit to a classroom in nearly any high school today will find teachers using many approaches to bring their lessons to life—from group laboratories, to media demonstrations, to hands-on data collection. Yet as lively as these lessons appear, teaching and learning challenges persist in the typical practice of science education. In brief, the challenges are:

1. **Classrooms lack a range of effective methods for understanding and addressing student misconceptions:** Students come to school with fragmented and incorrect ideas about how things work; these ideas can persist unless instructional programs provide multiple opportunities for teachers to understand them, tease out their conceptually useful features, and, ultimately, develop a clearer picture of how to use the ideas as starting points for helping students build richer, more sophisticated conceptual understandings.(Gil-Perez, Carrascosa, & Aikenhead, 1990)

2. **Laboratory learning activities often fall short on supporting scientific inquiry practices:** The learning activities done as labs often emphasize procedural knowledge and serve only to confirm facts about science rather than to introduce students to the process of inquiry that scientists use to establish what they know.(Singer, Hilton, & Schweingruber, 2005)

3. **Assessment is inadequate:** Tests that do no more than assess students' recollection of scientific facts fail to provide a valid profile of the full range of outcomes of a science curriculum, including conceptual understanding and scientific reasoning skills. They also do not provide feedback that science teachers can use to make decisions on what to do next, or to guide student reflection on their learning. (Quellmalz & Haertel, 2004; Singer et al., 2005)

4. **Classroom systems for fostering scientific argumentation are weak:** Teachers lack resources to engage students in rich dialog about their

reasoning in science across a variety of classroom activities.(Berland & Reiser, 2009; D. Clark et al., 2010; Standards, 2011)

Over the past 20 years, researchers have focused their efforts on these challenges with some promising results, but most science teachers have incorporated only a scant proportion of those research findings into their teaching. Technology is an important lever for addressing these challenges, if it is incorporated appropriately into the teaching/learning process.

Overview of This Paper

This paper provides an overview of five of the core practices of science identified by the NAS analysis, how they could be implemented using the Nspired Learning platform, and relevant evidence of effectiveness. Our focus is on the four teaching challenges described above, as they occur when teaching the five core practices. Within this focus, we examine four issues in teaching practice, how research on technology has addressed the issues, and give examples to illustrate the potential of the Nspired Learning platform:

First, we discuss using **probeware to collect and graph data** from sensors. We discuss the research-based evidence for the use of such tools to support student learning; teachers can use this evidence to make the case to administrators for purchases of probeware.

Next, we discuss **analyzing and interpreting data; developing and using models; using mathematics, information and computer technology, and computational thinking.** We examine some research-based best practices and give examples. Then we conclude with a brief summary of evidence of effectiveness of these practices.

Then, we discuss **engaging in argument from evidence**. We summarize research defining argumentation, and give an example of how to interpret that research and incorporate it into daily teaching practice. We also discuss how **formative assessment** can support teaching and learning of scientific practices.

Finally, we conclude by describing one important best practice for science teaching that teachers already use to improve student learning and that lends itself easily to the Nspired Learning platform**: offloading unnecessary cognitive complexity during scientific inquiry.**

Collecting Data with Probeware

Probeware, also known as “microprocessing-based labs” (MBL) or “calculator-based labs” (CBL), has been used by science educators for more than 30 years (Tinker, 2000). The term “probeware” describes tools that connect a sensor, or “probe,” to a computer or calculator, which allows students to observe real-time data. For example, the Nspired Learning technology includes a special attachment with multiple ports for connecting a wide variety probes, as well as easy-to-use data collection and graphing software. This can be used in conjunction with the digital video display capabilities of the system, to facilitate observation of the measured phenomenon.

Science teachers generally use probeware to teach (1) interpretation of line graphs, and (2) abstract concepts, such as motion (Svec, 1999), chemical composition, or temperature. Probeware provides students with graphic representations of scientific phenomena that are abstract and difficult to grasp (Tinker, 2000). Physics concepts about motion can be illustrated through real-time graphs (Svec, 1999): with such graphs, students can detect a movement, graph it, and then adjust the movement to see the change on the graphic display. This type of rapid feedback allows for a quick cycle of trial and error, which is believed to permit students to learn a concept with fewer misconceptions (Tinker, 2000) Probes let students gather and graph data accurately and quickly, therefore spending less time in data recording and plotting. Probes thus promote the long-term pedagogical goal of "inquiry -centered" science classes (Roschelle, 2003).

An example of data collection is an enzyme catalysis lab, shown on the next page.

1: Students set up the experimental apparatus. Students connect the EasyLink to the TI-Nspire, and then they connect the Gas Pressure Sensor to the EasyLink. They should set the TI-Nspire to collect data every 1 second for 30 seconds.

2: Students then attach the tube to the sensor, and then they attach the black stopper to the tube.

3: Students use the graduated cylinder to measure 5 mL of hydrogen peroxide and pour it into the flask.

4: Students then draw 1 mL of the enzyme suspension into the syringe.

5: Then students click start on the TI-Nspire and immediately add the enzyme suspension to the flask. They should then quickly put the stopper firmly in the mouth of the flask. Students should view the collected data in the *Vernier DataQuest* application on page 2.1.

6: Students then fit a line to the data using the **Moveable Line** tool. The best analysis of the graphical data is done by only including the initial "uphill" part of the graph. Sometimes, this includes only 5–10 seconds of the graphed data.

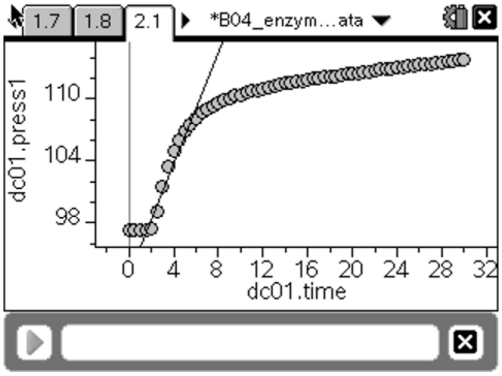

Figure 1: Example of data capture in an enzyme catalysis lab experiment.

Currently, more than 60 kinds of probes can be used to capture data for science classrooms. Typically, the probeware's hardware converts a physical property (e.g., heat, sound, motion, distance, pressure, voltage, temperature) into an electrical property (Tinker, 2000), and then a software interface displays the resulting data on a computer or calculator. Examples of probes produced by Vernier Software and Technology, a leader in the probeware field, include probes for biology (e.g., Blood Pressure Sensor, Conductivity Probe, Temperature Probes, EKG Sensor, pH Sensor), chemistry (e.g., Gas Pressure Sensor, Salinity Sensor, Voltage Probe, Electrode Amplifier.), and physics (e.g., Motion Detector, Light Sensor, Sound Level Meter, Rotary Motion Sensor) (see www.vernier.com).

Best Practices

Probeware supports a range of research-based instructional practices. Three guidelines have been published recently by the National Science Teachers Association (Bell, Gess-Newsome, & Luft, 2008):

1. Use the tool when it will give you the best data.
2. Use probeware when finding a mathematical relationship among measured variables is desired.
3. Use probeware when short data collection time is an issue, and incorporate digital video when a view of the event with the data is essential for understanding the phenomena.[1]

There are additional research-based instructional advantages to appropriate use of probeware. For example, probeware can enhance formative assessment in the Nspired Learning classroom network, by providing teachers with data about students' evolving understanding of a topic; teachers can then adjust their lessons or feedback accordingly (Russell, Lucas, & McRobbie, 1999). Probeware also can foster collaboration among students as they collect data, supporting a constructivist learning environment that permits students to make sense of graphs and data together (Roschelle, 2003).

Evidence of Effectiveness

Research has shown that when teachers use probeware effectively, at every grade level their students learn more science than they do with paper and pencil methods. For example, one study showed a 27% to 71% improvement in learning of four probeware modules with students in grade 3-8 (Zucker, Tinker, Staudt, Mansfield, & Metcalf, 2008). Another study of high school physics students showed that using MBL led to greater improvement in creating comprehension of distance and velocity graphs than did students creating paper-and-pencil graphs; the study found that "real-time graphing" accounted for 90% of the treatment group's improvement (Brassell, 1987). A study of 14- to 16-year-old students who used MBL showed significantly higher skills in drawing and interpreting line graphs than students working without MBL (Friedler & McFarlane, 1997). At the undergraduate level, student skills for interpreting motion graphs were significantly more improved among MBL students than among physics students involved in a traditional lab (Svec, 1999). Other provocative, quasi-experimental or qualitative research suggests these MBL effects may extend to improving students' graphing skills and knowledge in biology (D. D. Adams & Shrum, 1990; Marcum-Dietrich & Ford, 2002).

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[1] Video is supported in Publish View, on the software versions of TI-Nspire

Analyzing and Interpreting Data

Science teachers have begun to develop new ways to use calculator and Internet technology to support their students' learning and sense-making in science. Some of these approaches:

- Help students quickly see and understand patterns in data (for example, by using TI-Nspire’s data analytics functions). This understanding lays the groundwork for classroom argumentation.
- Help students make more accurate applications of scientific theories to real-world phenomena and complex real-world data sets (easily handled by TI-Nspire), thus offering some insight into student misconceptions and grounding their understanding in real-world experience.
- Help students navigate a complex, multilayered conceptual domain. For example, some teachers have used TI-Nspire documents to create a set of science-specific calculations and graphs for their students. These custom-made graphs and calculations can be used to highlight a key conceptual relation during classroom laboratory activities without bogging students down in the details of recording data.
- Use motion and image displays and simple visualization tools to help demonstrate scientific phenomena. Such tools permit exploration and testing of students’ initial theories about how things work, and help students see what would otherwise be invisible (too big, too small, too fast or too slow). These types of tools are available in TI-Nspire handheld or software versions.

All these practices resonate with instructional strategies found effective in science education research. Because science teachers already use these popular practices, supporting them all in a single, simple-to-use tool such as TI-Nspire could facilitate their broader and more consistent use.

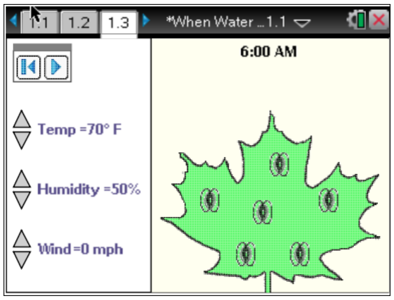
Now, we can examine the research-based best practices which have been discovered for these practices.

Best Practices

Seeing and understanding patterns in data; applications; real-world data sets. Although American high school science classes increasingly focus on hands-on data collection, teachers still find it difficult to engage their students in reasoning and argumentation around data and evidence. To stimulate such activity, research indicates that students must be able to understand how scientific data are structured to support “knowledge building” (Richard Lehrer & Schauble, 2002). Making the conceptual relations clear in data is one way to help students understand the underlying structure, and tools that quickly transform data into interpretable representations help students see the big ideas.

Three examples will show how this works in practice. In a climatology unit, technologies with capabilities similar to those available in TI-Nspire CX have been used to create scientific overlays that employ graphs, color, and motion to illustrate patterns in complex data sets. (Pea, Edelson, & Gomez, 1994) describe an example using different colors on a weather map to represent different temperature zones. Teachers then could engage students in exploring patterns across data sets, setting the stage for investigating the conditions that cause severe storms, movements of weather fronts, and flooding.

In biology, teachers have generated distinct types of simple X-Y coordinate graphs to spotlight key conceptual relations. Biology students often need to compare relations over time between two climate phenomena, such as temperature, humidity and wind compared to transpiration. To do so, having a graph with information on two opposing vertical axes with the time information along the bottom horizontal axis is helpful (see figs. 2 and 3, below).



Temp =70° F

Humidity =50%

Wind=0 mph

Figure 2: In this simulation, students can vary temperature, humidity and wind to see the effect on transpiration, plotted in Fig. 3.

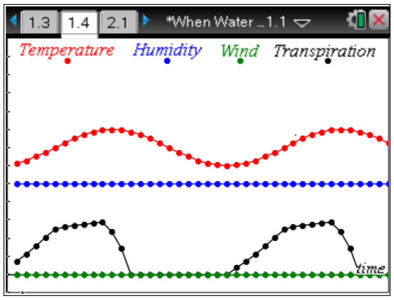


Figure 3: Resulting multi-axis data plot for the transpiration simulation.

Complex, multi-layered conceptual domains. Moreover, biology teachers frequently need students to compare sets of data so that they can see related patterns over time, such as how tides ebb and flow by the hours of the day, or how the populations of predator and prey species rise and fall. Teachers may want students to understand how different enzymes are affected differently by temperature. These needs can be met either through a screen that displays multiple tables or that permits overlays of data (see figs. 4 and 5, below).

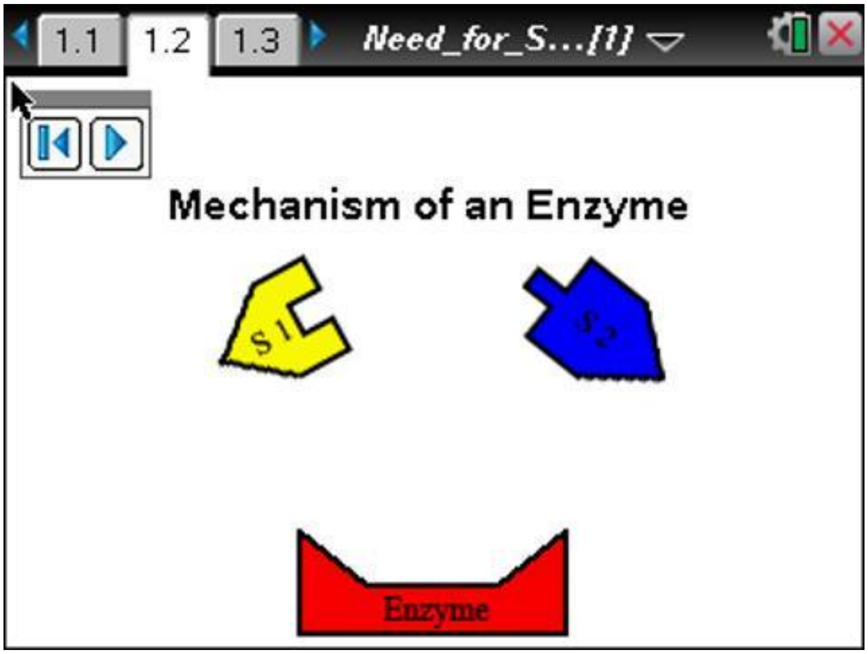


Fig. 4: Dynamic simulation of enzyme catalysis.
By clicking on the "play" button in this simulation, students can observe the action of the enzyme.

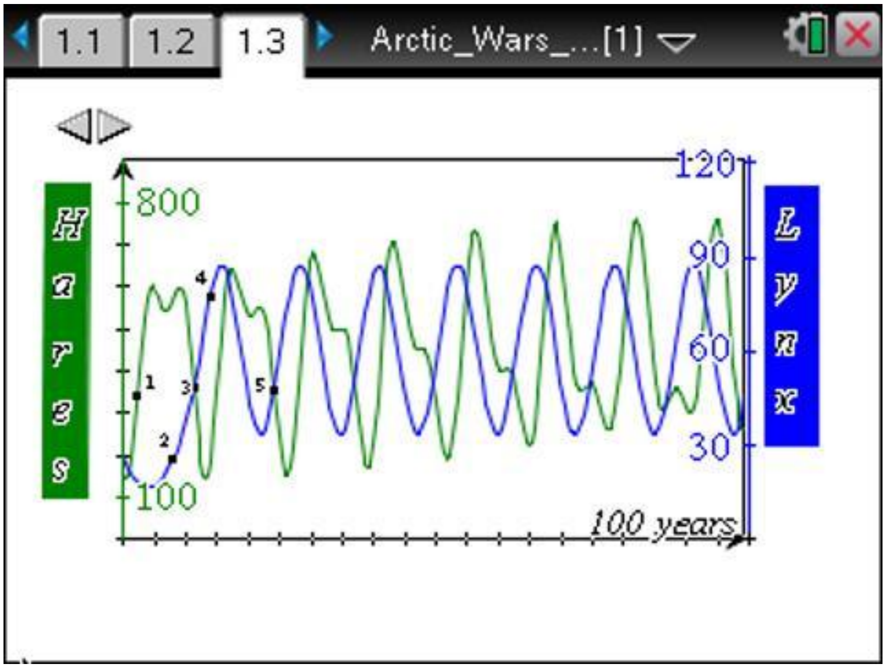


Figure 5: Data plot from a simulation of the interaction of populations of Hares and Lynx in an Arctic ecosystem.

Science teachers seeking to focus student attention on key concepts also want software that permits easy conversions between different scientific units. Providing this function in a one-stop tool would allow students to see the bigger picture and to think and reason through the concept (V. Michalchik et al., in press; Schank & Kozma, 2002). A function library for this purpose could easily be created as a TI-Nspire document, and distributed to students.

Still and Motion Images. It is well-known that students can develop misconceptions by over-generalizing fragments of scientific ideas across the real-world phenomena they observe and experience (Smith, diSessa, & Roschelle, 1993). Research indicates that video tools become particularly pedagogically useful when accompanied by tools that permit students to manipulate the images to understand patterns—speeding the images up, slowing them down, or freezing frames according to consistent intervals (Rubin, 1993) (see below).[2]

By having such video and motion tools, teachers have a greater chance to address the challenges students face when connecting scientific concepts with real-world phenomena (W. K. Adams et al., submitted). Teachers can use such videos to launch a discussion of how to apply scientific ideas to observable real-world phenomena. Typically, science teachers use small pieces of science films or YouTube clips to demonstrate cell division, chemical reactions, or digestion [3]

There is a fundamental distinction between the design and use of images for entertainment, artistic and illustration purposes, and their use for instructional purposes. The effectiveness of still and motion images designed for instruction has long been understood, and with the advent of computer technology, the combination of still and motion images, sound, text and interaction into *multimedia* has led to a synthesis of this research into general design principles (Mayer, 2005). For science teachers, some of the most important principles for still and motion images have been derived from this work by Bell and Park (ch. 2 in (Bell et al., 2008)):[4]

1. Selected photos and videos must specifically illustrate the targeted content and match the instructional goal.
2. Ensure that students have a meaningful interaction with images or video.
3. Make sure the image or video supplements your good instruction, not replaces it.

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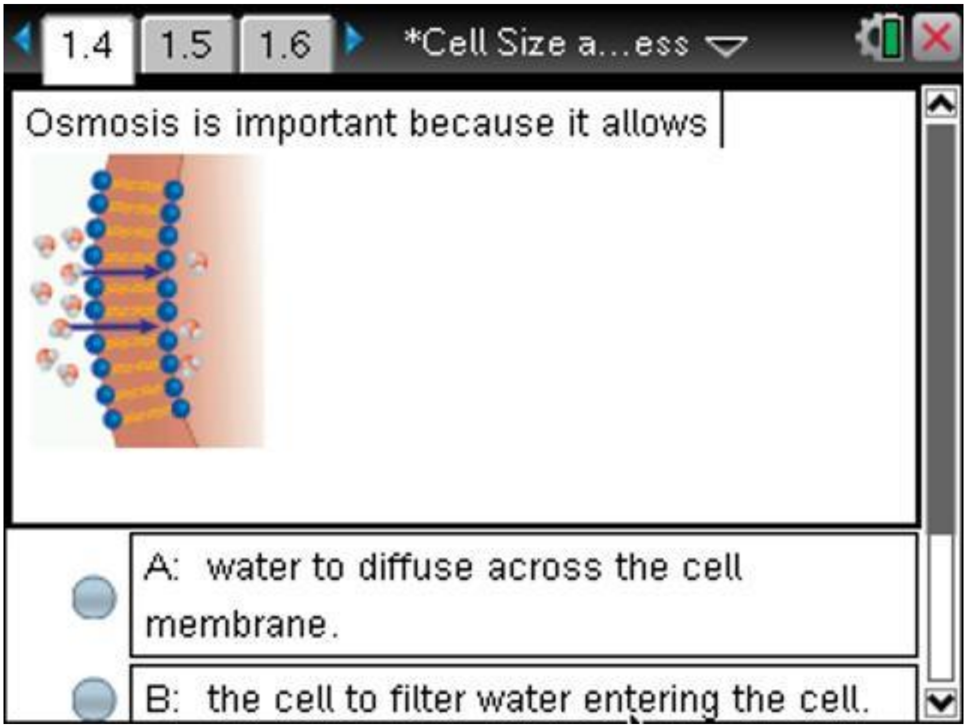
[2] In TI-Nspire PC and Mac versions, video is available in PublishView; .TNS-based simulations (which run on all platforms) can support speeding up and slowing down.

[3] Dynamic videos and are available online, and can be incorporated into TI-Nspire PublishView documents. Many interactive applets of scientific phenomena are available (for example, as .TNS files to run on TI-Nspire). Images can be incorporated into TI-Navigator Question App libraries (see Fig. 5).

[4] Still images are supported by the Nspired Learning platform on all platforms, and video images are supported in PublishView on laptops.

4. Model appropriate use and attributions of copyrighted digital images and video.



Osmosis is important because it allows

○ A: water to diffuse across the cell membrane.

○ B: the cell to filter water entering the cell.

Figure 6: Example of a Ti-Navigator Question App using an image. The question app supports a wide range of open-ended and selection question formats.

Evidence of effectiveness

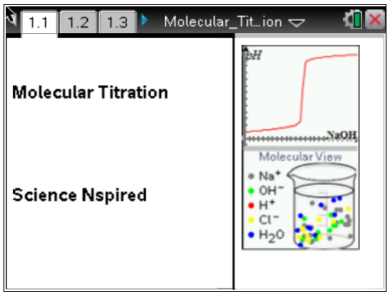
A large body of research on effectiveness of still and video images has accumulated since World War II, beginning with work on film and photos, then adding TV, and most recently, computer-based multimedia. A recent review of research (R. C. Clark & Mayer, 2002) cites a series of 11 studies on the combination of words and graphics which showed improvements of 55% to 121% when instructionally appropriate graphics were used with words alone. Another review of research by Tobias and Fletcher in (Mayer, 2005) reports these studies showed a median gain in retention of 23% (effect size of 0.67).They caution, however, that “research findings…suggest that augmenting text with pictures does not facilitate learning uniformly and that the multimedia principle is not enough by itself to ensure receiving full benefit from the use of pictorial information” (p. 122). The remainder of the book is structured around a group of design principles for effective application of still and motion images to instruction.

There is additional evidence suggesting that motion (video or computer animation) may be superior to still images in some circumstances. The Tobias and Fletcher review cites evidence from studies (Mayer & Anderson, 1991) showing that video animation with narration was superior to words only in producing both retention and transfer. They also report on two additional studies (Al-Seghayer, 2001; Hanley, Herron, & Cole, 1995) suggesting that video may be superior to still photos. However, they caution that more research is needed to understand the circumstances under which this is true.

Modeling and Simulation: Using Multiple Representations to Foster Conceptual Understanding

Students often need help finding their way through complex scientific theories, especially theories that describe invisible or counterintuitive phenomena. Research suggests that modeling – construction of representations of the logical relationships of components in the system under study – is a critical skill (Richard Lehrer & Schauble, 2006, 2009). Models usually link multiple representations of concepts, constructs, relationships and data. They help students explore and understand the relations between different concepts, and are necessary in developing questions and predictions in scientific reasoning.

Modeling and multiple representation tools have been shown to foster student discussion (Schank & Kozma, 2002). For example, the simulation shown below allows students to simultaneously view graphical and molecular representations of titration, as they vary the levels of the ions in the beaker.



Molecular Titration

Science Nspired

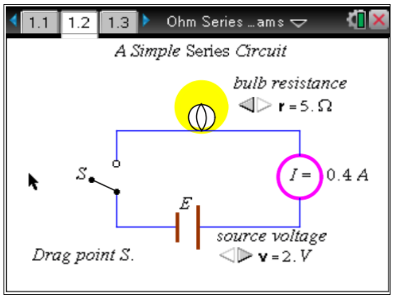
Simpler applications of multiple representation also benefit students. For example, TI-Nspire's ability to connect tables, graphs, and functions allows students to create graphical models of data, or to frame equations which describe and predict the relationships the students theorize. Indeed, the integration of geometry features into the graphing capabilities of TI-Nspire makes it possible to simply build many simple simulations directly within TI-Nspire. More complex simulations can be programmed using TI-Basic and the Lua programming languages.

Best Practices

Teachers can incorporate modeling into the curriculum in a variety of ways (Richard Lehrer & Schauble, 2006, 2009; Oh & Oh, 2011). . A simulation can be a physical microcosm (as in a working model of planetary motion in the solar system), a representational system (as in a circuit simulator or an ecosystem builder), or a syntactic model (as in a graphical object which the student drags, as it generates a data table):

- *Physical Microcosms* can be miniatures (or enlarged representations) of systems, such as the solar system, or a cellular organism. Moving models (simulations) can show the dynamic relationships of the physical components, while static models show only the physical components in relation to one another. As students' understanding of the system grows, they can modify and add to their models the additional relationships they learn of.

- *Representational Systems* are used to select and show only important attributes of the physical system, regardless of whether these attributes are implicit or explicit parts or attributes of the real system. For example, a map can show political boundaries as well as topography. A model of an electrical circuit can show the batteries, lights, and switches, but can also show voltage and current.



  In addition, representational systems can omit irrelevant and distracting detail, helping to focus attention on system attributes which are important for understanding. For these reasons, *unrealistic* models are often better for learning than *realistic* ones. Lehrer and Schauble (2006) cite research showing that even very young children are capable of distinguishing representations from reality in play contexts. The challenge teachers face is to let them do so in the classroom context, while also making appropriate connections to the real-world system being modeled.

- *Syntactic Models* go one step further, and present a completely abstract symbolic representation of the system. For example, a representational model of a falling body can show the body's motion, but this can also link the motion to a data table, and then to a syntactic model such as an equation with acceleration due to gravity, or a graph of velocity, or a vector graph of forces acting on the falling body. A schematic diagram of an electrical circuit can "behave" like an actual circuit, but without images of actual components, as shown by the Ohm's Law example above.

- *Emergent Models* are discovered through by fitting patterns to real-world data. Examples are the V-shape of a flock of migrating birds, which is apparent to a human observer (but not to the birds), or the behavior of the stock market, which can be described by an observer fitting a regression line (but the regression is not apparent to those on the trading floor).

Note that a *simulation* is a working model: the dynamic “behavior” of the simulation models some aspect of the behavior of the real system. Students who test their hypotheses by constructing their own simulation and comparing its behavior to their real-world observations are building emergent models in the form of simulations.

In their review of research on simulation, Bell and Smetana (ch. 3 in (Bell et al., 2008) make these recommendations for teaching best practices. These recommendations apply equally well to any kind of modeling, as to simulation:

1. Use computer simulations to supplement, not replace, other instructional modes.
2. Keep instruction student-centered.
3. Point out the limitations of the simulations.
4. Make content, not technology, the focus.

Evidence of Effectiveness

Bell and Smetana (2008) also review the evidence of effectiveness of appropriate use of simulation (and modeling) in science instruction. They highlight these conclusions:

- Gains in student understanding and achievement have been reported in general science process skills and across specific subject areas, including physics, chemistry, biology, and Earth and space science (Kulik, 2002)
- “Simulations promote learning about what-ifs and possibilities, not about certainties.” (Akpan & Andre, 2000) In a high school biology class, students using a simulation of worm dissection before an actual dissection learned more than those doing dissection alone (Akpan, 2002)
- A study of a computer-simulated chemistry experiment showed greater student achievement and process skills with the simulation than with hands-on labs (Geban, Askar, & Ozkan, 1992)
- A study of modeling ecological problems through simulation found that students were successful in designing, implementing and analyzing the results of three ecological problems, noting improvement even as the inquiry tasks became increasingly complex. Students also began employing more formal analytical strategies, rather than relying on trial and error. (Mintz, 1993)

Additional evidence is available on the importance of modeling in building understanding of scientific content and the process of scientific knowledge-building. For example, a project using emergent modeling to promote deep learning of subject matter material in plate tectonics to middle school students, and to foster knowledge of the meanings of models, showed that students built science inquiry understanding (Gobert & Pallant, 2004). In a study at an urban middle school using a curriculum featuring emergent modeling, the researchers report, "students wrote significantly better conclusions on the inquiry test and performed better on some of the far-transfer problems on the physics test…Correlational results, including significant correlations of pretest modeling and inquiry scores with posttest physics scores, suggest that developing knowledge of modeling and inquiry transfers to the learning of science content within such a curriculum. Taken together, the findings suggest that an emphasis on model-based inquiry, accompanied by the development of metamodeling knowledge, can facilitate learning science content while also developing students' understanding of the scientific enterprise" (Schwarz & White, 2005).

Argumentation and Explanation by Applying and Using Scientific Knowledge

The *Framework for K-12 Science Education* (2011) identifies argumentation as a core process of science and engineering, which should be incorporated in the curriculum at every level. In a recent paper sponsored by the Board on Science Education of the National Research Council, National Academies of Science, Clark et al define argumentation as, “the ability to engage in scientific argumentation (i.e., the ability to examine and then either accept or reject the relationships or connections between and among the evidence and the theoretical ideas invoked in an explanation or the ability to make connections between and among evidence and theory in an argument” (D. Clark et al., 2010). It is thus seen as central to scientific inquiry, and an important aspect of scientific literacy.

Best Practices

Clark, et al, review research on argumentation, and show that students use these processes:

- Make sense of the phenomenon under study
- Generate a sufficient and useful explanation
- Justify their explanation using appropriate evidence and reasoning
- Evaluate the validity or acceptability of an explanation

In a conventional science classroom, students rarely have the opportunity to learn these skills. More specifically Berland and Reiser (2009) find that students consistently use evidence to make sense of a phenomenon, and they can articulate the explanation, but they don’t consistently engage in the last two processes (by persuading others).

Skillful teachers can convert these four processes into four basic types of discussion questions:

- What did you see happening? (Making sense)
- Why did it happen? (explanation)
- What tells you this is why it happened? (justifying)
- How do you know this is the best explanation? (evaluating)

Classroom discussions and worksheets can be built around questions such as these. For example, teachers can pose the questions using the questioning features of TI-Navigator, and in the ensuing discussion, challenge students to persuade each other of their answers. Worksheets implemented in PublishView can be used to scaffold all four types of activities for small group collaboration. Additional suggestions for practice using worksheets and discussion are in

(Ross, Fisher, & Frey, 2009). A review of four more sophisticated and complex computer-based tools for scaffolding argumentation is in (D. Clark et al., 2010).

Using Formative Assessment to Promote Argumentation and Explanation

In the average classroom, technology for assessment in science has not changed much beyond simple tests and quizzes. Teachers can easily implement these assessments written for their curriculum on the Nspired Learning platform, with considerable advantages of convenience and time saving.

At the same time, however, cognitive science researchers have developed ways to make assessments do more than assess students' recall at the end of a unit. These innovative assessments reveal how students develop complex conceptual knowledge and skills. They not only deepen teachers' understanding of how students learn, but also help students continuously track their own progress. One of the most powerful practices is to use **formative assessment** as part of the instructional plan. As we define the term, formative assessment (also called **assessment *for* learning**) is embedded in the fabric of the teaching/learning process, rather than being a discrete event (as with summative assessment, also called assessment *of* learning) (P. Black, Harrison, Lee, Marshall, & Wiliam, 2004; Paul Black & Wiliam, 1998; Heritage & Stigler, 2010). The purposes of formative assessment are often substantially different from the familiar test or quiz. They include:

- Eliciting ideas (such as predictions, hypotheses, and explanations) and promoting scientific discussion
- Use of diagnostic questions to identify and correct misconceptions by eliciting student thinking
- Promoting argumentation among students
- Adaptive learning

Four examples illustrate some ways these purposes can be implemented using TI-Nspire with the TI-Navigator classroom network:

- **Eliciting Ideas:** Using the *draw prediction* feature (in the DataQuest application) prior to beginning data capture for an experiment captures a student's hypothesis. The data subsequently captured may support or refute the hypothesis. Another example is the use of *Quick poll* to capture the thinking of students while learning is happening, by asking generative (divergent reasoning) questions to elicit a range of responses which can then be evaluated and compared by the class.

- **Using diagnostic questions:** Quick poll questions embedded throughout a lesson can give teachers the instant feedback necessary to know if intervention to correct misconceptions is necessary.

- **Promoting argumentation among students**: using navigator as a way for students to share their data (through file exchange and simultaneous display of screens), students can discuss conclusions based on their data and compare to data and conclusions from another group.
- **Adaptive learning:** the Contingent Pedagogies Project, now in progress at SRI International, Inc., applies a facet-based perspective to unpack student conceptions in Earth Science and to design diagnostic questions to be used formatively. The diagnostic questions are posed using student response systems with capabilities which are among those offered by TI-Navigator. Using the system, a teacher devises a question, such as “Why are most of the volcanoes of the world in the ‘Ring of Fire’?” and provides a list of possible answers to the questions from which students select. All students then use the networked handheld input devices to answer the question. Once all students have answered, teachers can project a histogram showing the distribution of student responses, using the classroom communication system. To support teachers in promoting scientific practices such as asking questions, co-constructing representations of the world, constructing and critiquing arguments, and communicating and interpreting science, discourse moves adapted from *Ready, Set, Science* (Michaels, Shouse, & Schweingruber, 2007) are used in conjunction with diagnostic questions. Many of these moves are intended to shift responsibility for thinking to students and to encourage students to engage one another’s ideas in the context of developing and critiquing scientific models and arguments

Further discussions of these techniques are available in (Beatty, Gerace, Leonard, & Dufresne, 2006; W. Penuel, 2008; W. R. Penuel et al., (submitted)).

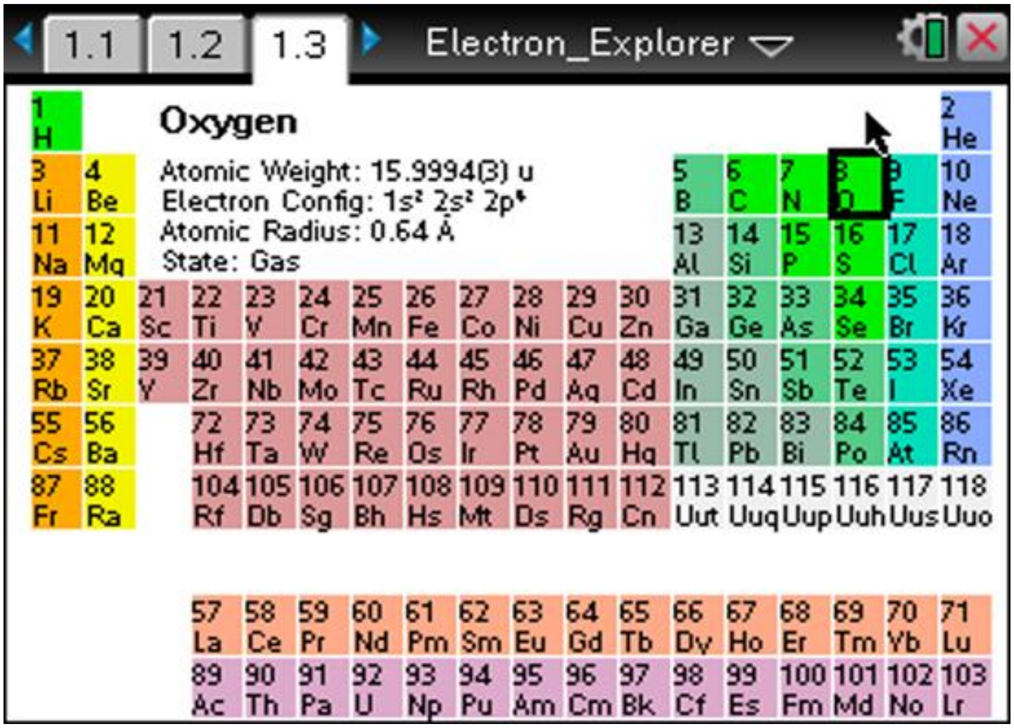
Evidence of Effectiveness

When used with these techniques, there is high-quality experimental evidence from a large-scale study that teaching with TI-Navigator increases student achievement by an average of 14% (Owens et al., 2008; Pape et al., (in press)). Additional evidence is reported in (Abrahamson, 2006; Judson & Sawada, 2002).

Offloading Unnecessary Cognitive Load During Scientific Inquiry

Advances in cognitive science have led to the realization that, as powerful as the brain is, it has limitations in its ability to process simultaneous tasks requiring conscious thought. As a consequence, a task such as complex scientific reasoning has been shown to be quite capable of overloading available cognitive resources (Paas, Renkl, & Sweller, 2003; Sweller, Ayres, & Kalyuga, 2011), thus slowing or preventing efficient learning. Research shows that complex cognitive tasks such as scientific reasoning comprised of a variety of subtasks. Some of the subtasks involve high-level reasoning skills, and tend to be the focus of teaching and learning. However, others of the subtasks are more routine, such as recalling factual information, calculating and graphing, recording data and creating analytical plots, and the like. Technology can be used to take over many of these low-level tasks. This frees up the student's cognitive resources for application to the high-level reasoning task at hand.

An example will illustrate how this works. TI-Nspire includes a program that permits an automated "look up" of the molecular structure of each chemical element by clicking on an element's notation on the periodic table. By clicking back and forth between the periodic table and the molecular structures, students can explore the rationale behind periodic families and the placement of elements on the periodic table. Students can see the relationship between elements and their electron configurations.



Oxygen

Atomic Weight: 15.9994(3) u
Electron Config: $1s^2 2s^2 2p^4$
Atomic Radius: 0.64 Å
State: Gas

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Research shows that a tool such as this can effectively offload the low-level cognitive tasks of recalling the properties of elements, thus freeing students to more efficiently engage in high-level tasks of reasoning within Chemistry, such as understanding molecular structure and behavior (Vera Michalchik et al., (in press); Schank & Kozma, 2002).

Concluding Remarks

While science teachers often use technology to automate (and thus offload) the low-level tasks of data collection and computation, the purpose of this paper has been to describe four research-based practices which support five of the science processes emphasized in current curriculum thinking: **planning and carrying out investigations** (in particular, **data collection**); **analyzing and interpreting data; developing and using models; using mathematics, information and computer technology, and computational thinking; engaging in argument from evidence..** For each of these processes, we have briefly summarized current research defining the process, discussed research on best teaching practices, and presented evidence of effectiveness. In addition, we have discussed research on two important applications of this technology to the classroom: formative assessment, and offloading unnecessary cognitive tasks.

Throughout, we have given examples using the technologies of Nspired Learning, comprising TI-Nspire software and handhelds, accessories for supporting probeware, the TI-Navigator wireless classroom network, and other accessories. By doing so, we have shown how these technologies opens to science teachers and curriculum developers a learning environment capable of supporting many learning activities which are among the most important in current science curricula aimed at 21st century skills. Support for the emerging Common Core State Standards in Science is an important capability of this family of technologies.

Our hope is that readers of this paper will see how the Nspired Learning platform can be leveraged as part of a plan to improve science curriculum and teaching, when used in the ways suggested by the research we describe, by teachers trained in these techniques. We believe that these applications, which align with the research summarized in this paper, will serve as the basis of advanced science teaching, in a unified classroom, lab, and field environment.

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