A Reflective Discourse on Science Learning and the Merits of Simulation

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Introduction

It is widely understood that science and technology education are central to the development and prosperity of all modern societies. Embedded in the context of recent U.S. science education reform initiatives from the national to local levels is the belief in and commitment to adequate science instruction for all students. Also, it is clear that learning science necessitates a move from passivity to activity and that students develop a better understanding of science through inquiry and exploration. The common thread envisioned by these reform efforts is an improved and uniform level of scientific literacy, which, according to the National Science Education Standards, is generally defined to mean “that a person can ask, [and then] find or determine answers to, questions derived from curiosity about everyday experiences” (1996, p. 22). Further, the authors of Science for All Americans (Rutherford & Ahlgren, 1990, p. v) state that science education should equip our students “to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. America’s future—its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities—depends more than ever on the character and
quality of the education that the nation provides for all of its children.” Of course, a scientifically literate citizenry electorate is essential and fundamental to this globally-shared vision.

While it appears there is general consensus among educators that a primary mission of K-12 science education is scientific literacy, debate wages over how to best achieve this elusive goal. Certainly, there is no magic bullet, no one-size-fits-all strategy that can accomplish this task. Yet, there is a great deal to be gained from a continuous and vigorous discussion on learning and knowledge acquisition: schools and educators must evolve to teach more effectively, and, in turn, assist in moving their students toward a more definitive and measurable outcome known as scientific literacy.

Learning Science

Learning science should be a natural or automatic result of a coherent and relevant curriculum, since it concerns our most basic and common physical daily life experiences. Yet, it is clear that the majority of textbooks and associated activities do not reflect the cohesiveness and interdisciplinary dynamics of the field. The world is rich in natural and technological phenomena that await exploration, description, and demystification. However, student interest and appreciation for the universality and practicality of the subject is virtually non-existent. This is attributed, in part, to an enculturation process that socializes students (and their teachers) to believe, conclude, or assume that science is an inherently difficult and remote subject to learn, understand, and value. The question must be asked, how can educators capture the excitement of learning and investigating science for themselves and their students? What must take place so that teachers and students will commonly and enthusiastically echo Nobel-Prize winning physicist Richard Feynman’s sentiments: “The world looks so different after learning science” (1968, p. 319).

We know that learning both occurs deliberately and not as deliberately as an individual interacts with and experiments upon the corresponding environment. However, students are not taught or adequately encouraged to contextualize science explorations (in a classroom or independently) and place this knowledge in a framework in which they can attach their own reality and prior experience. Frequently, they grow discouraged or frustrated in their efforts to make real sense of science. Over time, their alienation and dislike of the subject grows. As an example, one can readily see the learning estrangement when teachers prematurely lecture on complex science topics or over-emphasize abstractions, theories, and vocabulary. Learner frustration is a natural manifestation produced by
teaching practices that render the subject foreign to the learners’ present reality. In these scenarios, the teacher is trying to “pour” knowledge into the mind of the student or into the “tabula rasa” (blank slate) as the 17th century philosopher, John Locke, would say. In this “passive mode” of learning, students take on a role in which they are “told” what they, as learners, “need to know” by their teachers. As early as 1902, the educator John Dewey recognized that this type of instruction was ineffective and asserted that the student was not a “docile recipient of facts” (p. 3). The explorative and creative aspects (through inquiry and problem solving) of the subject are lost on the student-as-spectator model of learning.

Constructivist educators would agree with Dewey that “knowledge cannot be transferred to a passive receiver. It has to be actively built up by every single knower” (von Glaserfeld, 1992, p. 171). Therefore, knowledge cannot exist without individual construction; knowledge is constructed, not acquired (Byrnes, 1996). Piaget (1980), regarded as the founder of constructivism, states:

Knowledge does not result from a mere recording of observations without a structuring activity on the part of the subject. Nor do any a priori or innate cognitive structures exist in man; the functioning of intelligence alone is hereditary and creates structures only through an organization of successive actions performed on objects. Consequently, an epistemology conforming to the data of psychogenesis could be neither empiricist nor pre-formationist, but could consist only of a constructivism. (p. 23)

Constructivism allows that the learner utilizes prior knowledge to make sense of new explorations, and thus “construct” meaning by synthesizing experiences, both past and present. Indeed, student learning outcomes are quite sensitive to the breadth and quality of each student’s prior experiences. Individuals with rich and varied concrete experiences of natural phenomena, tools, and the inner workings of machines, for example, are more readily guided in their own attempt to understand and relate to abstractions like force, energy, and momentum. In this way, constructivism helps inform our enthusiasm for the learning potential and fits seamlessly with classroom science explorations. For the ever-increasing fraction of students who are experientially ill prepared for understanding the abstract concepts, connections, and themes of science instruction (Kelly, 2000), exploration offers some much-needed concrete references. Likewise, students’ prior experience impacts the benefit they get from reading and listening to explanations of science topics, but the basic constructivist tenets do not align as well with the written word. Lowery (1998) submits that written formats (e.g., textbooks) offer minimal assistance to learner understanding because symbols/words do not
represent reality, and words cannot be manipulated by investigation. For a student to understand or even interpret what a symbol means depends on previous experiential knowledge. Printed words become powerful only when the text relates, enriches, and supports prior understanding and experience. When this “transfiguration” of knowledge occurs, the written word becomes a reorganization of “old” knowledge with “new” connections established (Lowery, 1998). It is significant to reiterate again and again that knowledge, communicated from writer-to-reader, speaker-to-listener, or teacher-to-student does not, in and of itself, connote a successful transmission of meaning to the learner. Meaning is created through personal experience and viable connections (Kelly, 2000; Redish, 2003; von Glaserfeld, 1992) made by the individual’s “subjective knowledge of the world” (Saunders, 1992, p. 136).

How then can teachers best utilize this information on learning to the most benefit of their students? First, the teacher must recognize that they must help students make “good” connections between what the student already knows, or thinks he knows, with new knowledge. “Old” knowledge may be faulty and require reconstruction (Anderson & Smith, 1987). Consequently, an effective teacher must create a learning environment that encourages this conceptual change in learning possible for the student. A teacher that “allows students to retain their naïve conceptions is doomed to produce only misunderstanding or rote memorization” (Anderson & Smith, 1987, p. 91). To assist the student and further his/her understanding, a teacher must know that it is not the amount or quality of information that hinders student performance; it is the organization of that information which is lacking. Teachers, themselves, must learn how to organize their own knowledge and experiences before they can then instruct students on how to do the same. Bransford, Brown, and Cocking (2000) write:

Experts’ abilities to reason and solve problems depend on well-organized knowledge that affects what they notice and how they represent problems. Experts are not simply ‘general problem solvers’ who have learned a set of strategies that operate across all domains, whether chess, electronics, mathematics, or classroom teaching... An emphasis on the patterns perceived by experts suggests that pattern recognition is an important strategy for helping students develop confidence and competence. These patterns provide triggering conditions for accessing knowledge that is relevant to a task. (p. 36)

So, effective teachers must model sense-making and pattern-seeking behaviors and expertly guide students to realize, directly confront, and rethink their own misconceptions. In this way, effective teaching of science should incorporate thoughtful, reflective experiences that promote
student hypothesizing and questioning to foster genuine interest and curiosity in, and a deeper understanding of, the subject. The investigative processes should be replicable, so that students organize the information they receive, recognize the patterns and relationships in doing the science, and, finally, make associations with prior understanding, regardless of the content. Over time, this type of training should become routine. Teaching practices that facilitate such involvement should help to make learning science more natural, less frustrating, and less alienating. Science should then take its place as a central part of a relevant and meaningful curriculum and not be regarded as a peripheral and difficult yet ‘important’ subject.

We are faced with significant challenges if we are to make progress toward improved scientific literacy. Despite the universality of natural and technological phenomena in our lives, an increasing fraction of our students have limited exposure to the kinds of hands-on, concrete experiences, coupled with timely, truthful, and simple explanations, which combine to prepare students for further science instruction. To counter this, we need well-trained, confident teachers, strategic curricula, and appropriate learning materials that together can invigorate science education and reverse declining achievement in and increased student alienation from science.

**Science the Subject**

Teaching science is distinguished from other subjects because it is a “unique” combination of content lecture and laboratory explorations. No other content courses are delivered in such a format. Given this fact, why are laboratory experiences important for science instruction? The Board on Science Education of the National Research Council (2005) wrote:

In our review of the literature we have identified a number of science learning goals that have been attributed to laboratory experiences, including:

- enhancing mastery of subject matter;
- developing scientific reasoning;
- understanding the complexity and ambiguity of empirical work;
- developing practical skills;
- understanding the nature of science;
- cultivating interest in science and interest in learning science; and
- developing teamwork abilities. (p. 3)

Also, that “some of the science learning goals presented above, particularly understanding the complexity and ambiguity of empirical work, can be attained only through laboratory experiences” (NRC 2005, p. 4).
Yet, too often, the laboratory component is much less than we hope for. The Board argues that while “the state of the research knowledge base on laboratory experiences is dismal… even so, [it] suggests that the laboratory experiences of most high school students are equally dismal” (NRC 2005, p. 11).

Among other recommendations based on recent research, the Board recommends “integrated instructional units [that] connect laboratory experiences with other types of science learning activities,” where students “are engaged in framing research questions, making observations, designing and executing experiments, gathering and analyzing data, and constructing scientific arguments and explanations” (NRC 2005, p. 4). Yet, it is typical that lecture (aka direct teaching method) alone is the traditional delivery method utilized by teachers to impart knowledge (the theoretical and factual content) to the students, and laboratory exercise is viewed only as an activity that reinforces the content delivery. Based on this tendency toward lower expectations and encouraged passivity, it may certainly be reasonable to surmise that lecture would have no place in the constructivist model. However, a teacher lecture followed by directed activity and class discussion lends itself well to scaffolding, questioning, and hypothesizing, which in turn, allows for a better understanding of the topic (Kelly, 2000). Further, while laboratory experiences, typically including “hands on” practical applications or demonstrations of course content, have been the supposed experimental, constructivist portion of the learning activity, they do not typically fare well under closer scrutiny. In many instances these “hands-on” experiences are nothing more than a mechanical regurgitation of an earlier lecture, and subsequently do not contribute much to the individual learner’s conceptual understanding (Handelsman et al., 2004; Redish, 2003).

The inquiry model, which by outward appearance aligns with the constructivist perspective, offers a viable alternative to the traditional direct teaching model (lecture-lab), if utilized appropriately. With the inquiry approach, students act independently in their research (e.g., lab exercise, project, etc.) to offer pragmatic solutions to a posed problem. The National Research Council (1996) presents inquiry as “activities …in which they (students) develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (p. 23). Further, the inquiry advocacy aligns with the basic premise of scientific literacy and that is students “ask, find, or determine answers to questions derived from curiosity about everyday experiences” (National Research Council, 1996, p. 22). With the inquiry model, the teacher’s role transforms into that of a facilitator, that is, someone who guides activity, but
does not engage in controlling student investigation or thought as is the case with the direct teaching model.

Though much has been done to emphasize the basic tenets of inquiry and the “doing” of science in the classroom, the fact is, much of science teaching, in the name of inquiry, has been reduced to hands-on activity that frequently becomes monotonous and mundane. Redish (2003) asserts that students “can actively work with equipment and still not learn very much” (p. 182). The purpose of doing science is to enable learners to make connections, observe patterns and relationships, and reflect upon the exploration, but in many instances, and for whatever reason, this is not being done in the school environment. Somehow, even the scientific method has become mechanized and rote in the science classroom.

By its very name, inquiry suggests probing and investigation beyond the scope of the traditional science classroom. True science inquiry possesses a certain amount of serendipity that all too often practically vanishes in a classroom. Granted, the topic totality of science is far-reaching and nebulous and cannot always be confined or categorized in a classroom exercise. Yet, much of science instruction, even inquiry-based, has become exactly what it was never intended to be—an overly structured classroom event. If the approach is to survive satisfactorily and intact, then educators should be alerted to the need for a variety in instructional routine, including the utilization of technology to explore a world of science and problem solving that might not otherwise be available to the student learner.

**Technology and Teaching Science**

Today’s fast-paced world is saturated by almost daily advancements in technology. Computers and technological tools have become commonplace among scientists, researchers, and the scientific community. Meanwhile, science educators struggle to stay abreast of change. In some instances, teachers are unprepared to utilize technology in their classrooms because they have little or no training and are fearful of what they do not know. Hurd (2000) acknowledges that the challenge in science education is now connecting technology, as a knowledge-producing system, with those who are a part of the knowledge-using system.

As with anything progressive, technology is viewed with both reverence and skepticism. Robertson (2003) observes that technology is enticing because it represents an answer (rightly or wrongly) to educational ills. She states:

Information technology promises to deliver more (and more important) learning for every student accomplished in less time; to ensure “indi-
vidualization” no matter how large and diverse the class; to obliterate the
differences and disadvantages associated with race, gender, and class;
to vary and yet standardize the curriculum; to remove subjectivity from
student evaluation; to make reporting and record keeping a snap; to
draw out reluctant and disinterested parents; to keep discipline problems
to a minimum; to enhance professional learning and discourse; and to
transform the discredited teacher-centered classroom into that paean of
pedagogy; the constructivist, student-centered classroom. (p. 284-285)

Proponents of technology use in the science classroom would debate
that technology has few shortcomings in spite of the criticisms leveled. Keller
and Keller (2005) maintain that teachers have failed to offer students
classroom experiences that incorporate scientific inquiry and appropriate
methodology. They list a multitude of mistakes that teachers commit in
the name of science which impact student learning negatively, such as:
“inadequate exposure to science research, fear that experiments will fail
unless carefully scripted, belief in efficacy of their current techniques,
unfamiliarity with technology, and a need by teachers to know all of the
answers” (pp. 4-5). In either case, Rieber (2005) argues that current evi-
dence suggests that technology has had little impact on education despite
the money spent on it, and that the biggest impact of technology can be
seen outside of traditional schooling, particularly in electronic gaming.
Further, he notes that most of the research on multimedia in education
has focused on “scripted” or explanatory media and less on media that
provides experiential learning. He observes that “of course, explanation
and experience are important in education, but advocates of games, simul-
ations, and microworlds put experience first with explanations serving a
supporting role” (p. 550). Microworlds are a form of exploratory learning
simulation considered to have “important” embedded ideas while games
are simulations that are designed and found to be intrinsically motivating
and enjoyable (p. 558).

Even as we note a history of overly optimistic predictions of technological
transformation in education, we contend that computer program simula-
tions have emerged as “cutting edge” tools that promote science learning in
different contexts and introduce students to new and unique experiences
that cannot be replicated effectively through classroom investigations or
other activities. Simulations are considered an important step in presenting
real world science experiences that otherwise could not be performed in a
classroom. Further, some educators espouse that simulations extend the
range of student investigations by making the “abstract” experience more
concrete and by providing immediate feedback about the exploration, which
is often better than what teachers explain through lecture and reinforce-
ment activity (Ronen & Eliahu, 2000; Trumper, 2003).
Simulation: What Is It and How Does It Work?

What exactly is a computer simulation? It is a mathematical model which produces an artificial representation or re-creation of real world (and/or imagined) phenomena, as encoded in a computer program. Simulations can be divided into two types: operational and conceptual. The operational simulation is used for experiential learning and is often procedural in design. Conceptual simulations, discussed in this paper, are grounded in investigative activity; that is, students perform experiments, set/change variables, collect data, make inferences, and draw conclusions based upon their experiences. It is this conceptual simulation model which is rooted in the tenets of constructivism (de Jong & van Joolingen, 1998). A constructivist would offer that the simulation provides a platform for the learner to construct/modify new understandings as he/she connects with prior knowledge in an effort to make sense of the new “information.”

All simulations share a common goal and that is, to be successful, they must “incorporate effective features so that the users’ attention is focused on the essential learning that they are undertaking” (Yeo et al., 2004, p. 1357). The success of students who use simulations is directly related to the details of the program and the way in which it is used and presented (Steinberg, 2000). Yeo et al. (2004) believes that the obligation of the simulation is to “provide students with enabling experiences in authentic applications rather than situations without a context, and on cultivating learning processes rather than assimilating isolated knowledge items” (p. 1352).

Early computer simulations involved limited control over variables and parameters. These simulations promoted a more “step by step cookbook” approach for students to follow in order to reach a specific objective (Windschitl & Andre, 1998). However, more recent computer based simulations allow for a greater input control over variables and parameters. The number of variables present and the relations between the variables is the simulation’s degree of elaboration (White & Frederiksen, 1990). The greater the degree of elaboration created, the greater the level of complexity of the simulation. The manipulation of the variables to produce a new effect allows the learner to predict and test a wide variety of situations within the confines of the simulation. Throughout the testing of a concept within the simulation the learner maintains an active role of changing the variables in order to predict how the alteration will affect the outcome (Windschitl & Andre, 1998). The added control over variables and parameters being tested allows the student user to manipulate the virtual environment and conceptual
theories through means that are either not available within the real world or are otherwise inaccessible to the student. Windschitl and Andre write “the ability of simulations to portray phenomena and allow users to interact with the dynamics of a model system . . . creates [a] unique way of helping learners conceptualize” (1998, p. 148).

As simulations become more sophisticated, they are used in an increasing number of ways to support and/or study science learning and to tackle the variety of science learning goals discussed previously. For example, the combination of significant student user freedom and experimental simplification has led to the use of simulated microworlds to provide students and their teachers new opportunities for exploratory “scientific discovery” learning. These simulations allow students, with significant guidance, to generate their own hypotheses, develop and then interpret the results of experiments or tests, and regulate their own learning (de Jong & van Joolingen, 1998). Goldberg’s (2001) computer-supported learning environments provide good examples. His pedagogical approach was to have students extend their experience by collecting additional phenomenological data from simulations after comparable initial hands-on experiments (e.g. electrostatic charging by induction). Then conceptual models were made explicit with computer simulations so that students could collect “model-based evidence” (e.g. coloring model of electrostatic charge).

Finally, simulations allowed multiple representations of the same or related concepts (e.g. currents in a circuit shown by arrows, values, bulb brightness, and compass needle deflection). In another example, Finkelstein et. al. (2005) have shown that improved (faster) subsequent circuit construction and challenge problem solutions were achieved by university-level students who used a sophisticated circuit simulation rather than to spend time with an equivalent equipment-based lab activity. It is clear that we should expect that stand-alone simulations, simulations in combination with hands-on equipment, and simulations integrated into other learning activities will experience the same developmental trends of ever-increasing interactivity, realistic rendering, and user-savvy design sophistication, as evident in software development led by the computer and video gaming industry.

Kulik (2002, p. 3) states that “simulation programs seem to focus on higher level instructional objectives” rather than regular tutorial (explanatory) programs as the simulations focus on problem solving and so help students as they work to integrate facts and concepts into their previously existing schemata. In such programs (like Goldberg’s) students are invoking the simulation in order to develop their own refined conceptual understanding of the material, often by predicting outcomes
based upon their preferred method of problem solving. Should the results of the prediction come back outside the student’s accepted conceptual understanding, progress is blocked and so dissatisfaction occurs (Windschitl & Andre, 1998). Further testing within the simulation framework can result in confirmation or denial of the prediction based upon the learner’s existing understanding. It then becomes the teacher’s responsibility (opportunity) to clarify misunderstandings via the progression of the activity, and/or through discussion and further investigation.

The Merits, Detractions, and Feasibilities of Simulation

Can simulations help students to learn science? Student performance, as a result of simulation interaction, is variable as reported in the research. Some findings are favorable regarding student achievement and the use of simulations (Sethi, 2005; Steinberg, 2000; Stieff & Wilensky, 2003; Zacharia, 2003) while other reports reflect little or no difference in student accomplishment when compared to the traditional classroom (Robertson, 2003). In the early developmental stages of simulations, criticism was directed at the rigidity and unrealistic representation of the operational real-world (Feisel & Rosa, 2005). However, improved computational technologies now allow the creation of simulations that more nearly emulate the real world, or at least, important aspects of real physical experience. Probably pilot training models serve as the best example of a real-world application; even the pilots “can attest to the realism that simulation can provide” (Feisel & Rosa, 2005, p. 125).

In this real-life context, sophisticated simulations have had a dramatic impact on pilot education and testing. So, is it reasonable to expect or hope that science education will be similarly impacted by simulation use? We argue that simulations, if appropriately designed, will help students to bridge the gap between their concrete experiences and the abstract principles often associated with science concepts taught in the classroom. An instructor may patiently and repeatedly explain the desired concrete-to-abstract relationship to students, yet research indicates that the conventional lecture approach is not a successful model to use when trying to prepare learners with the necessary cognitive tools for conceptual understanding (Stieff & Wilensky, 2003). The interactive experience and the program visualizations in a simulation, coupled with appropriate classroom instruction, can provide the student with the necessary concrete information to develop new insights about the concept and so, make progress in aligning science abstractions (Zacharia, 2003). Another benefit to simulation use is the immediate feedback provided during learner interaction with the program (Sethi, 2005).
This immediate feedback is in direct contrast to the several day communication delay associated with the traditional lab report. Perhaps the strongest case for the rapid development and promotion of simulations is those classrooms where laboratory activity is virtually non-existent. In such cases, simulations may provide a solution for science teachers who, lacking sufficient support to have appropriate space, time, or budget would otherwise “do without” or somehow try to “make do.” Also, if simulations are integrated with more traditional published teaching materials, their use will be strongly encouraged. For teachers who lack the confidence to discuss and guide science explorations with their students, even with simple or common materials, it seems that carefully crafted simulations with built-in pedagogical support should be very helpful. Further, with this kind of support, it may be possible that such teachers could gain the confidence to branch out from the simulations to related real-world explorations.

So, we see that simulations could provide learning opportunities by penetrating into classrooms that would otherwise have minimal science activities. Still, while simulations can help teachers address a number of science learning goals, simulations are not the real world and exploring a model is not the same as experiencing natural phenomena. Simulations would, for example, be a very artificial way to teach the real-world skill of trouble-shooting or sorting out the ambiguities that come naturally with real equipment and non-ideal conditions. Simulations are intended to emulate real world phenomena and provide meaningful and engaging experiences for students, but they are not, however, to replace laboratory investigations altogether (Keller & Keller, 2005).

Simulations are utilitarian with numerous possibilities for the science classroom including:

- pre-lab exercises to provide students with an idea of the real lab that they will encounter;
- alternative options to the traditional lecture delivery format including immediate feedback during and culminating the simulation activity;
- a bridge between the concrete and abstract principles of science;
- virtual reality experiences that train students in proper scientific techniques and procedures; and
- substitutes for laboratory experiments.

In spite of all the positive benefits that may be attributed to simulations, one must pose a very basic question: If students perform computer simulations, are they learning to do science or only learning about science? This same question should be posed for student participation in
real-world laboratory and other science learning activities. Although simulations have evolved and advanced from their less than sophisticated beginnings, clear limitations do exist. Most technology advocates would issue assurances that using a simulation is doing science because programs are explicitly interactive, even if there is no “physical” manipulation of real world variables. Learners are can be engaged in making predictions, hypothesizing, testing variables, and collecting and analyzing data. Both experimental lab and simulation advocates would argue that, in each circumstance, the learner is able to challenge existing conceptual understanding through the process of predicting and evaluating possible outcomes created by his/her own devices in the laboratory setting.

Learning often requires a totality experience which even state-of-the-art simulations cannot provide. There are no tactile or kinesthetic facets; students are unable to feel, taste, smell, or touch their materials to obtain an understanding of what it is really like to perform the experiment. Further, simulations are inductive in nature, and while educators strongly support the inquiry process as a strategizing or problem-solving technique, the “big picture” is not always self-evident to learners. Clearly, the teacher must provide intervention so that students gain a better understanding of their simulation experiences.

**Conclusions**

Computer-based simulations have established their role in the science classroom as an interactive interface for student investigation. As the learner is able to manipulate the parameters of their virtual environment within the simulation students construct new understanding of the underlying concepts through inferring and predicting possible outcomes. Although an artificial construct, the usefulness of computer-based simulation lies within the dynamics of the real world theory/model it endeavors to reproduce. Simple simulations may be viewed as more tutorial; objective oriented “cook-book” style method with no place in a constructivist setting. However, increasingly sophisticated and interactive simulations (e.g., with greater user freedom due to numerous adjustable variables or parameters) increases the likelihood that the constructivist educator would utilize it in the classroom setting.

Should, or can science simulations replace the real laboratory experience? No, but they definitely have a place in the learning process and should be viewed as supplementary tools to classroom instruction and laboratory experiences. Finally, we argue that well-designed simulations can help students “interpret the underlying scientific conceptions of the
program, compare them with other their own conceptions, formulate and test hypotheses, and reconcile any discrepancy between their ideas and the observation in the simulation” (Zacharia, 2003, p. 796). The research clearly supports the use of simulations as a tool to improve science learning, not as a way to supplant the teacher or the laboratory experience.

As technologies become more commonly used in the K-12 environment, it is recommended that educators continue to examine the potential benefits and detrimental effects of simulations on student learning. Furthermore, teachers must become more skilled in their use of technology and should act as change agents in the classroom as they elaborate on the science topic and reinforce main points so that students may build on their own knowledge and move beyond the boundaries presented through the simulation.

References


