Effective and Appropriate Uses of Educational Technology in Science Classrooms

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Many scientists, science educators, and professional organizations recommend the use of educational technology as a powerful tool to enhance student learning of science (American Association for the Advancement of Science (AAAS), 1997, 1998; International Society for Technology in Education (ISTE), 2002; National Council for Accreditation of Teacher Education (NCATE), 1997; National Research Council (NRC), 1996; National Science Teachers Association (NSTA), 1998). Position statements and suggestions regarding the integration of educational technology in secondary science teaching preparation include: a) providing skills training for educational technology in the context of science teaching; b) modeling appropriate uses of educational technology; c) providing opportunities for teachers to practice using educational technology in science teaching; d) providing opportunities for preservice teachers to observe inservice teachers model educational technology use for science teaching; and e) providing opportunities for preservice science teachers to use educational technology during their student teaching experience (American Association for the Advancement of Science (AAAS), 1997, 1998; Colburn, 2000; International Society for Technology in Education (ISTE), 2002; National Council for Accreditation of Teacher Education (NCATE), 1997; National Research Council (NRC), 1996; National Science Teachers Association (NSTA), 1998; Parkinson, 1998; Willis & Mehlinger, 1996).

Flick and Bell (2000) offer five guidelines consistent with national reform goals in science education for using technology in the science classroom:

1. Technology should be introduced in the context of science content;
2. Technology should address worthwhile science with appropriate pedagogy;
3. Technology instruction in science should take advantage of the unique features of technology;
4. Technology should make scientific views more accessible;
5. Technology instruction should develop students' understanding of the relationship between technology and science (Flick & Bell, 2000).

Flick and Bell assert that traditional approaches to technology education for preservice and inservice teachers focus primarily on a set of technology tools to which the science content must be adapted and often produce contrived activities for the classroom teacher. The authors recommend that teachers start with the science content and then select appropriate technology tools to teach their lessons.

Image-rich technology resources such as Internet web sites and presentation software, as well as digital cameras, digital microscopes, and spreadsheets offer 21st century science teachers a wealth of new resources to aid in classroom instruction. The primary tasks accomplished with these technology tools include offering visual representations of abstract science concepts or concepts that are difficult or impossible to see. These visual representations offer the potential to link classroom topics to historical events, to connect seemingly archaic classroom topics to more relevant real world contexts, to provide views of the inner workings of objects too small to see (cells or micro-organisms), to provide animations of processes impossible to see in the classroom (earthquakes, lunar cycles, star constellations and movements), to supply images of objects too dangerous to see (explosive chemical or nuclear reactions, volcanoes), and to supply images of life cycle changes too subtle to observe (the changes in the chrysalis of a caterpillar or the germination of a seed). In addition, spreadsheets can facilitate the analysis of data and the preparation of graphics to help students visualize the relationships between data points collected during classroom experiments.

An example of effective and appropriate use of educational technology in a biology classroom is illustrated in the following vignette about Amy, a preservice teacher engaged in her student teaching at a suburban high school in central Virginia. Amy participated in a preservice preparation program at the University of Virginia that included a sustained, integrated educational technology program. A detailed description of this program can be found in Bell & Hofer, 2003.

As the observer enters, ninth-grade students work in small groups at their low hexagonal laboratory stations finishing up an acid-base pH laboratory activity. The second half of a 90-minute block period has just begun. Amy directs her class to complete their laboratory activities so they can proceed to their acid rain and butterfly inquiry studies.

Amy demonstrates the digital camera that students will use to record images during their inquiry projects. She explains that making observations is an important part of the scientific process and asks her students what kinds of pictures they think would be helpful to document the acid rain plant experiment. Students suggest close-up images of the plants at different stages of growth, images of the plants being treated with acid rain, images showing how the watering system functions to provide the plants with moisture and images of the lighting system. Amy asks students at different laboratory tables to volunteer to take pictures using the digital camera and writes their names on the board next to the images for which they are responsible. Next, Amy holds up the camera, shows *students how to insert the 3.5 inch floppy disc for storing the images, shows the power button, the screen, the zoom button and how to take pictures. Amy tells her students that the digital images are part of the inquiry project and that students will receive credit for taking pictures with the camera.*

Student groups retrieve their seedlings from the side of the room. This is day five of their experiment and the Wisconsin Fast plants are about 5 cm tall. The class is highly engaged in the task of observing the characteristics of their plants and recording information in their journals. They use rulers to measure height and discuss the best way to obtain uniform measurements from the class. Students measure from the ground to the growing tip of the plant, the apical meristem rather than to the tallest leaf. Students take turns using the digital camera to document plant growth by taking pictures with metric rulers held next to the plants. Students also take pictures of the watering system and the lighting system used for their plants. One third receives pH 4.5 water, one third receives pH 5.5 water and the remaining third receives pH 6.5 water. The leaves of some of the plants show an unhealthy yellowish coloration.

After students finish with their plants, Amy invites them to return to their seats. Students view an image of a large tree with a heart carved in its trunk on the overhead projector. Amy asks students to estimate the distance of the heart from the ground. Then she asks the students where the heart carving will be in 20 years. Students realize that the carving will be at the same height from the ground, because plant growth occurs at the apical meristem of the tree.

> *Amy next introduces the butterfly metamorphosis inquiry project. She asks her class to compare the experimental design of the acid rain project with this new observational project. In addition to the acid rain journal, students will record data daily in a butterfly journal. They will take pictures using a digital camera, record behavior using a digital microscope with both snapshot and video capture capability, make sketches by hand, make measurements, and record data describing the behavior of their caterpillars. The organisms are in small pillboxes with letters of the alphabet written on top to help students identify their individual caterpillars. A large zippered netted cage about 0.75 meters tall and 0.5 meters deep with a white plastic tubing frame is set up in the classroom with the butterfly's host plants growing inside. Amy reviews the difference between observations and inferences with her students before she distributes the pillboxes to her students. Students make their first journal entry describing their caterpillars and take pictures with both the digital camera and the digital microscopes (Irving, 2003).*

Amy taught her students to use digital cameras and digital microscopes to collect electronic images documenting the development of both the plants and the caterpillars during these two inquiry projects. At the end of the projects, Amy's students entered their plant height data in an Excel spreadsheet and produced growth charts for each of the three different acid rain treatment groups. The students wrote descriptions of their projects, selected and annotated time-lapse and still images, and created a class web site publishing the results of both the acid rain experiment and the butterfly observational study for their families and school community.

Amy understood the power of images to involve her students in these inquiry projects to study the often hidden processes of nature. She stated that the inquiry butterfly project especially helped students learn about the process of metamorphosis, about the diet of caterpillars and butterflies, and about the birth of deformed as well as normal butterflies. The time-lapse feature on the digital camera captured the process of a caterpillar creating its chrysalis, an amazing event for her secondary students to witness. When asked to describe her most successful use of educational technology, Amy replied:

> The whole research project, especially with the butterflies; Using the QX3 [digital microscopes] and the digital cameras to document the … observational study. And …I hope they realized that showing what they saw, communicating their results was one of the most important parts of the project. And that was where the web site came in; And where taking pictures and documenting the research came in…. Kids were really impressed when they saw the time-lapse videos that they took of the caterpillar turning into the chrysalis; like they were just totally blown away that they could do that. (Amy, post interview); (Irving, 2003)

In these lessons, Amy engaged her students in inquiry learning using educational technology to gather, analyze, and communicate data. She connected the inquiry projects to her daily lessons on cell theory and cell functions to help students understand the relevancy of their lecture and reading materials. The contrast between plant and animal cells was reinforced for her students as they conducted inquiry projects with both butterflies and mustard plants. Amy took advantage of the unique features of educational technology tools to collect images as data in long-term inquiry projects in her biology classroom.

Effective technology integration in teaching and learning asks: How can educational technology support student learning? Unfortunately, some educators and technology advocates prefer to approach technology integration with the question: How can we use this new technology in classrooms? The fundamental difference in approach is the focus on human information processing as the central driving force in technology use in classroom instruction rather than the focus on the capabilities of the technology. Effective educational technology inclusion is consistent with how the human mind works to learn and process information.

Two opposing views of learning theory posit the learner as either: a) a passive recipient of knowledge transferred from teacher to learner, or b) an active sense maker who seeks to personally construct a coherent mental representation of the learning task. In the passive-recipient mode, the teacher's job is to transmit knowledge, more information is better, responsibility for learning rests with the teacher, assessment measures repetition and remembering, and educational technology becomes an electronic information delivery system. In the learning-as-knowledge-construction mode, information presentation needs to support student meaning-making, students are active participants in the learning process, the teacher serves as a facilitator to student sense-making, the responsibility for learning is shared by student and teacher, and assessment measures remembering, understanding, and application of knowledge. Educational technology in the knowledge-construction mode offers instructional strategies to present information and provide guidance on how to process that information, what to take note of, how to mentally organize the information, and how it relates to prior knowledge.

Mayer, in his text *Multimedia Learning* (Mayer, 2001), suggests a theory of multimedia learning based on research in cognitive psychology and education on how people learn. Three assumptions form the basis of his theory: (1) humans have dual-channels for information processing, visual/pictorial and auditory/verbal; (2) each channel has a limited capacity for processing information (cognitive load theory); and (3) effective learning includes active learner involvement in a coordinated set of steps to select relevant words from text or narration, to select relevant images from presented representations, to organize both verbal and visual input, and then to integrate the verbal and visual representations with prior knowledge in a particular learning domain.

Mayer suggests that people are more successful learners when presented with both words and pictures than just words alone. He argues that words and pictures are not equivalent, but that they provide complementary information to the learner. Mayer carefully distinguishes between media effects (using a computer screen to provide the image versus using a textbook image) and multimedia effects (using two media such as text and images versus just using a single media such as text). The issue is not about comparing delivery systems for information (an information-delivery view of learning), but rather about selecting instructional strategies based on research on how students learn. Mayer argues that his cognitive theory of multimedia learning rests on a knowledge construction view of learning and is consistent with the findings of cognitive research. He suggests that instead of comparing instructional mediums for maximum effectiveness, researchers should seek instructional techniques that help learners learn more effectively based on prior research findings. The issue is not computers versus books, but how images, text, and narration support both retention and application of knowledge.

Educational technology provides 21st century teachers with unprecedented access to images, representations, and auditory materials for classroom use. Knowledge of best practice with images, text and narration in classroom instruction could help teachers maximize the impact of these new powerful tools for lesson design. Use of illustrations as decoration (for entertainment or interest but little instructional benefit), as representations of real world people or objects (fungi, lab equipment, scientists), for organizational purposes (periodic table, maps, charts), or as explanations (stepwise depiction of a complex process such as photosynthesis or meiosis) are a few of the possible uses of images in lessons. Methods to maximize both information delivery and knowledge construction in classrooms would help students to both remember and apply the knowledge learned in school (Mayer, 2001).

Although the inclusion of images with words or text has been shown to enhance student learning, differences in multimedia messages produce different learning results. Mayer (2001) suggests six principles of multimedia design that could be used to guide lesson design with images, narration, and text:

1. Spatial contiguity principle: Spatial relationships between words and pictures impact learning. Placement close to each other is better than far apart. Learners need to use fewer cognitive resources to select, organize, and integrate relevant information when it is concentrated in a small visual field.
2. Temporal contiguity principle: presentation of words and pictures at the same time is better than successive presentation. Learners are more likely to hold both images and text in short term memory at the same time and have a better opportunity to select, organize and integrate relevant information.
3. Coherence principle: Extraneous visual and auditory material competes for attention and can have a negative impact on learning. Cognitive resources are diverted by extraneous materials. Selection of critical elements for learning and exclusion of extraneous elements is an important facet of lesson design.
4. Modality principle: Animation supported with spoken narration is more effective than animation with written text. Presentation of pictures and words can overload the visual channel. Presentation of text auditorially maximizes the use of both learning channels, the visual/pictorial and the auditory/verbal.

5. Redundancy principle: Animation and narration is more effective than animation, narration, and text. Text and pictures presented together can overload the visual learning channel.
6. Individual difference principle: Multimedia design effects are particularly effective for novices who are high-spatial learners. Experts or high-knowledge learners use prior knowledge to compensate for poor multimedia design. High-spatial learners demonstrate greater ease in mentally integrating visual and verbal representations. Low-spatial learners struggle to hold images and verbal representations in memory in order for integration to occur.

For a science teacher, the role of technology is necessarily secondary to the primary focus of instruction on science content. In addition to the knowledge of their content domain, pedagogy and curriculum, classroom teachers need what might be called ePCK, electronic pedagogical content knowledge to integrate educational technology with science instruction. (Shulman, 1986) first described pedagogical content knowledge (PCK) as the teacher's knowledge of the best ways to teach particular concepts, which concepts are apt to cause confusion for students, common misconceptions for students in a particular domain, a wide variety of teaching strategies from which to select the best approach for a particular student group, the most appropriate demonstrations, laboratory exercises, analogies, images, diagrams, problems, and explanations to make a subject transparent for students. Expert teachers not only have a deep conceptual understanding of the topics they teach and are familiar with a wide variety of teaching strategies, but they also understand why students are challenged when learning some topics and not others.

Three important aspects of ePCK for technology integration in science teaching include: a) being able to recognize the connection between the science content, the technology, and the pedagogy for a lesson; b) being able to apply multimedia principles to design an effective lesson; and c) being able to recognize how the technology can help students dispel or avoid misconceptions by using educational technology in a particular domain. As with science content, it is not enough to have a deep understanding of educational technology to be able to teach effectively using these tools. Teaching involves discerning the learner's prior knowledge, recognizing how the new content fits with what is already known, and selecting the strategy to present each topic. Important elements of ePCK include teacher knowledge of educational technologies that offer compelling animations, interactive simulations, images, data collection and analysis tools, and communication tools that fit the curriculum topics for their science discipline.

The use of educational technology will not fit every domain in a science class equally well. Hands-on activities where students manipulate objects and create artifacts in the classroom offer compelling strategies for many science topics. However, many concepts in science are abstract, complex, invisible without the aid of special technologies, too large, too small, or too subtle for ordinary viewing in the classroom. Electronic technologies offer science teachers a host of powerful tools to help students visualize these concepts. Electronic pedagogical content knowledge involves the developing process of recognizing the parts of a science curriculum that would benefit from the use of educational technology tools to illuminate abstract or complex topics. Knowing about the technology, knowing how to use the technology, knowing how the technology fits the curriculum, knowing how the use of the technology contributes uniquely to the lesson and helps students avoid or dispel misconceptions regarding the content in a particular domain comprise important aspects of ePCK.

Information technology plays a central role in modern society. Preparing teachers for the workplaces of the 21st century requires them to be both technology-literate and prepared to integrate educational technology effectively and appropriately in their teaching. Success at this task represents a long-term commitment that requires the collaborative effort of schools of education, corporate and government partners, and local school districts. Students in preservice preparation programs need not only technology skills, but also exposure to lessons using educational technology in their college science content classes, opportunities to design and implement lessons using educational technology in their content area, opportunities to observe classroom teachers in K-12 schools modeling technology use, and experience during student teaching to practice designing and implementing lessons with technology elements. A sustained, integrated approach to technology use provides students with examples and opportunities to observe and participate in field based experiences. A multi-course curriculum like that modeled at the University of Virginia's Curry School of Education seeks to prepare technology-enriched preservice teachers and includes three separate courses as part of the educational technology infusion plan: (a) an introductory course with a technology component focusing on word-processing, telecommunications, and networking; (b) a one semester course in educational technology designed specifically for future science and mathematics teachers (taught by an instructional technology expert with science or mathematics teaching experience); and (c) a science methods class where the instructor integrates educational technology throughout (taught by a science educator with expert educational technology skills) (Irving & Bell, 2004).

Science teacher educators can effectively model educational technology use in their own teaching. Some examples include the use of concept mapping tools like Inspiration software to classify organisms or chemical substances, the use of virtual planetarium software such as Starry Night to model inquiry lessons on moon phases, or the use of spreadsheet programs like Excel to explore the relationship between average temperatures and the seasons in different parts of the world. Virtual earthquake web sites allow students to simulate earthquakes, collect data ,and triangulate to locate the source of the event. Virtual fieldtrips allow students to visit nuclear power plants, explore rock formations in distant regions of the earth, and visit outer space without leaving the classroom. Three-dimensional molecular models can be viewed on computer screens using molecular visualization tools such as the Chime plug-in.

In addition to modeling effective technology uses in the science methods classroom, science teacher educators can encourage preservice teachers to identify useful electronic resources, connect those resources to content standards, design lessons that incorporate the resources, and practice teaching the lessons. Practical issues of equipment access, equipment set up, platform compatibility, selection and use of electronic images and sound bytes, and design of multimedia presentations for classroom use should be encountered during preservice preparation rather than during actual teaching experiences.

In summary, scientists and science educators support the use of educational technology in science classroom teaching. Guidelines for appropriate and effective use of educational technology support a strategy of first identifying objectives for the science lesson and then matching appropriate technologies. A theory of multimedia learning that views learning as knowledge construction and rests on dual-coding theory, limited capacity (cognitive overload theory), and active learning provides guidance for educators to design effective lessons with modern technologies. The unprecedented availability of electronic images in the 21st century classroom and their use in multimedia learning represent powerful new tools for classroom teaching. Providing teachers with classroom computers and hoping they will figure out how to use them in classroom teaching results in infrequent and unimaginative technology use in teaching, as some have reported (Cuban, 2001; Cuban, Kirkpatrick, & Peck, 2001). Teachers need access to equipment, ready technology support, strong pedagogical content knowledge in their discipline and ePCK, electronic pedagogical content knowledge, to effectively integrate educational technology in the classroom. Sustained, integrated, preservice education programs can provide the conditions necessary to prepare a technology literate workforce for the classrooms of the 21st century.

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