National Center on Accessing the General Curriculum

NCAC

Virtual Reality/Computer Simulations

Curriculum Enhancement

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Virtual Reality/Computer Simulations

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Introduction

Many people associate virtual reality and computer simulations with science fiction, high-tech industries, and computer games; few associate these technologies with education. But virtual reality and computer simulations have been in use as educational tools for some time. Although they have mainly been used in applied fields such as aviation and medical imaging, these technologies have begun to edge their way into the primary classroom. There is now a sizeable research base addressing the effectiveness of virtual reality and computer simulations within school curriculum. The following five sections present a definition of these technologies, a sampling of different types and their curriculum applications, a discussion of the research evidence for their effectiveness, useful Web resources, and a list of referenced research articles.

Definition and Types

Computer simulations are computer-generated versions of real-world objects (for example, a sky scraper or chemical molecules) or processes (for example, population growth or biological decay). They may be presented in 2-dimensional, text-driven formats, or, increasingly, 3-dimensional, multimedia formats. Computer simulations can take many different forms, ranging from computer renderings of 3-dimensional geometric shapes to highly interactive, computerized laboratory experiments.

Virtual reality is a technology that allows students to explore and manipulate computer-generated, 3-dimensional, multimedia environments in real time. There are two main types of virtual reality environments. Desktop virtual reality environments are presented on an ordinary computer screen and are usually explored by keyboard, mouse, wand, joystick, or touchscreen. Web-based "virtual tours" are an example of a commonly available desktop virtual reality format. Total immersion virtual reality environments are presented on multiple, room-size screens or through a stereoscopic, head-mounted display unit. Additional specialized equipment such as a DataGlove (worn as one would a regular glove) enable the participant to interact with the virtual environment through normal body movements. Sensors on the head unit and DataGlove track the viewer's movements during exploration and provide feedback that is used to revise the display – enabling real-time, fluid interactivity. Examples of virtual reality environments are a virtual solar system that enables users to fly through space and observe objects from any angle, a virtual science experiment that simulates the growth of microorganisms under different conditions, a virtual tour of an archeological site, and a recreation of the Constitutional Convention of 1787.

Applications Across Curriculum Areas

Computer simulations and virtual reality offer students the unique opportunity of experiencing and exploring a broad range of environments, objects, and phenomena within the walls of the classroom. Students can observe and manipulate normally inaccessible objects, variables, and processes in real-time. The ability of these technologies to make what is abstract and intangible concrete and manipulable suits them to the study of natural phenomena and abstract concepts, "(VR) bridges the gap between the concrete world of nature and the abstract world of concepts and models (Yair, Mintz, & Litvak, 2001, p.294)." This makes them a welcome alternative to the conventional study of science and mathematics, which require students to develop understandings based on textual descriptions and 2-D representations.

The concretizing of objects – atoms, molecules, and bacteria, for example, makes learning more straightforward and intuitive for many students and supports a constructivist approach to learning. Students can learn by doing rather than, for example, reading. They can also test theories by developing alternative realities. This greatly facilitates the mastery of difficult concepts, for example the relation between distance, motion, and time (Yair et al.).

It is not therefore surprising that math and science applications are the most frequent to be found in the research literature. Twenty-two of the thirty-one studies surveyed in this review of the literature investigated applications in science; 6 studies investigated math applications. In contrast, only one study investigated applications in the humanities curriculum (specifically, history and reading). The two remaining addressed generalized skills independent of a curriculum area.

It is important to keep in mind, however, when reading this review, that virtual reality and computer simulations offer benefits that could potentially extend across the entire curriculum. For example, the ability to situate students in environments and contexts unavailable within the classroom could be beneficial in social studies, foreign language and culture, and English curricula, enabling students to immerse themselves in historical or fictional events and foreign cultures and explore them first hand. With regard to language learning, Schwienhorst (2002) notes numerous benefits of virtual reality, including the allowance of greater self-awareness, support for interaction, and the enabling of real-time collaboration (systems can be constructed to allow individuals in remote locations to interact in a virtual environment at the same time) (Schwienhorst, 2002).

The ability of virtual reality and computer simulations to scaffold student learning (Jiang & Potter, 1994; Kelly, 1997-98), potentially in an individualized way, is another characteristic that well suits them to a range of curriculum areas. An illustrative example of the scaffolding possibilities is a simulation program that records data and translates between notation systems for the student, so that he or she can concentrate on the targeted skills of learning probability (Jiang & Potter, 1994). The ability for students to revisit aspects of the environment repeatedly also helps put students in control of their learning. The multisensory nature can be especially helpful to students who are less visual learners and those who are better at comprehending symbols than text. With virtual environments, students can encounter abstract concepts directly, without the barrier of language or symbols and computer simulations and virtual environments are highly engaging, "There is simply no other way to engage students as virtual reality can (Sykes & Reid, 1999, p.61)." Thus, although math and science are the most frequently researched applications of these two technologies, humanities applications clearly merit the same consideration.

Evidence for Effectiveness

In the following sections, we discuss the evidence for the effectiveness of virtual reality and computer simulations based on an extensive survey of the literature published between 1980 and 2002. This survey included 31 research studies conducted in K-12 education settings and published in peer-reviewed journals (N=27) or presented at conferences (N=3) (it was necessary to include conference papers due to the low number of virtual reality articles in peer-reviewed journals). Every attempt was made to be fully inclusive but some studies could not be accessed in a timely fashion. Although the research base is somewhat small, particularly in the case of virtual reality, it provides some useful insights.

Virtual Reality

Numerous commentaries and/or descriptions of virtual reality projects in education have been published. Research studies are still relatively rare. We identified only 3 research investigations of virtual reality in the K-12 classroom: one journal article (Ainge, 1996) and two conference papers (Song, Han, & Yul Lee, 2000; Taylor, 1997).

Taylor's (1997) research was directed at identifying variables that influence students' enjoyment of virtual reality environments. After visiting a virtual reality environment, the 2,872 student participants (elementary, middle, and high school) rated the experience by questionnaire. Their responses were indicative of high levels of enjoyment throughout most of the sample. However, responses also indicated the need for further development of the interface both to improve students' ability to see in the environment and to reduce disorientation. Both factors were correlated with ratings of the environment's presence or authenticity, which itself was tightly associated with enjoyment. It's uncertain whether these technical issues remain a concern with today's virtual reality environments, which have certainly evolved since the time this study was published.

Whether or not virtual reality technology has yet been optimized to promote student enjoyment, it appears to have the potential to favorably impact the course of student learning. Ainge (1996) and Song et al. both provide evidence that virtual reality experiences can offer an advantage over more traditional instructional experiences – at least within certain contexts. Ainge showed that students who built and explored 3D solids with a desktop virtual reality program developed the ability to recognize 3D shapes in everyday contexts, whereas peers who constructed 3D solids out of paper did not. Moreover, students working with the virtual reality program were more enthusiastic during the course of the study (which was, however, brief - 4 sessions). Song et al. reported that middle school students who spent part of their geometry class time exploring 3-D solids were significantly more successful at solving geometry problems that required visualization than were peers taught geometry by verbal explanation. Both studies, however, seem to indicate that the benefits of virtual reality experiences are often limited to very specific skills. For example, students taught by a VR approach were not any more effective at solving geometry problems that did not require visualization (Song et al.).

Clearly, the benefits of virtual reality experiences need to be defined in a more comprehensive way. For example, although numerous authors have documented student enjoyment of virtual reality (Ainge, 1996; Bricken & Byrne, 1992; Johnson, Moher, Choo, Lin, & Kim, 2002; Song et al.), it is still unclear whether virtual reality can offer more than transient appeal for students. Also, the contexts in which it can be an effective curriculum enhancement are still undefined. In spite of the positive findings reported here, at this point it would be premature to make any broad or emphatic recommendations regarding the use of virtual reality as a curriculum enhancement.

Computer Simulations

There is substantial research reporting computer simulations to be an effective approach for improving students' learning. Three main learning outcomes have been addressed: conceptual change, skill development, and content area knowledge.

Conceptual change. One of the most interesting curriculum applications of computer simulations is the generation of conceptual change. Students often hold strong misconceptions – be they historical, mathematical, grammatical, or scientific. Computer simulations have been investigated as a means to help students confront and correct these misconceptions, which often involve essential learning concepts. For example, Zietsman & Hewson (1986) investigated the impact of a microcomputer simulation on students' misconceptions about the relationship between velocity and distance, fundamental concepts in physics. Conceptual change in the science domain has been the primary target for these investigations, although we identified one study situated within the mathematics curriculum (Jiang & Potter, 1994). All 3 studies that we directly reviewed (Jiang & Potter, 1994; Kangassalo, 1994; Zietsman & Hewson, 1986) supported the potential of computer simulations to help accomplish needed conceptual change. Stratford (1997) discusses additional evidence of this kind (Brna, 1987; Gorsky & Finegold, 1992) in his review of computer-based model research in precollege science classrooms (Stratford, 1997).

The quality of this research is, however, somewhat uneven. Lack of quantitative data (Brna, 1987; Jiang & Potter, 1994; Kangassalo, 1994) and control group(s) (Brna, 1987; Gorsky & Finegold, 1992; Jiang & Potter, 1994; Kangassalo, 1994) are recurrent problems. Nevertheless, there is a great deal of corroboration in this literature that computer simulations have considerable potential in helping students develop richer and more accurate conceptual models in science and mathematics.

Skill development. A more widely investigated outcome measure in the computer simulation literature is skill development. Of 12 studies, 11 reported that the use of computer simulations promoted skill development of one kind or another. The majority of these simulations involved mathematical or scientific scenarios (for example, a simulation of chemical molecules and a simulation of dice and spinner probability experiments), but a few incorporated other topic areas such as history (a digital text that simulated historical events and permitted students to make decisions that influenced outcomes) and creativity (a simulation of Lego block building). Skills reported to be improved include reading (Willing, 1988), problem solving (Jiang & Potter, 1994; Rivers & Vockell, 1987), science process skills (e.g. measurement, data interpretation, etc.; (Geban, Askar, & Ozkan, 1992; Huppert, Lomask, & Lazarowitz, 2002), 3D visualization (Barnea & Dori, 1999), mineral identification (Kelly, 1997-98), abstract thinking (Berlin & White, 1986), creativity (Michael, 2001), and algebra skills involving the ability to relate equations and real-life situations (Verzoni, 1995).

Seven (Barnea & Dori, 1999; Berlin & White, 1986; Huppert et al.; Kelly, 1997-98; Michael, 2001; Rivers & Vockell, 1987) of these twelve studies incorporated control groups enabling comparison of the effectiveness of computer simulations to other instructional approaches. Generally, they compared simulated explorations, manipulations, and/or experiments to hands-on versions involving concrete materials. The results of all 7 studies suggest that computer simulations can be implemented to as good or better effect than existing approaches.

There are interpretive questions, however, that undercut some of these studies' findings. One of the more problematic issues is that some computer simulation interventions have incorporated instructional elements or supports (Barnea & Dori, 1999; Geban et al.; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997) that are not present in the control treatment intervention. This makes it more difficult to attribute any advantage of the experimental treatment to the computer simulation per say. Other design issues such as failure to randomize group assignment (Barnea & Dori, 1999; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997; Verzoni,

1995) – none of these studies specified that they used random assignment) and the use of ill-documented, qualitative observations (Jiang & Potter, 1994; Mintz, 1993; Willing, 1988) weaken some of the studies. When several of these flaws are present in the same study (Barnea & Dori, 1999; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997), the findings should be weighted more lightly. Even excluding such studies, however, the evidence in support of computer simulations still outweighs that against them.

Two studies reported no effect of computer simulation use on skill development (Mintz, 1993, hypothesis testing; Vasu & Tyler, 1997, problem solving). However, neither of these studies is particularly strong. Mintz (1993) presented results from a small sample of subjects and based conclusions on only qualitative, observational data. Vasu & Tyler (1997) provide no detailed information about the nature of the simulation program investigated in their study or how students interacted with it, making it difficult to evaluate their findings.

Thus, as a whole, there is good support for the ability of computer simulations to improve various skills, particularly science and mathematics skills. Important questions do remain. One of the more important questions future studies should address is the degree to which two factors, computer simulations' novelty and training for involved teachers and staff, are fundamental to realizing the benefits of this technology.

Content area knowledge. Another potential curriculum application for computer simulations is the development of content area knowledge. According to the research literature, computer programs simulating topics as far ranging as frog dissection, a lake's food chain, microorganismal growth, and chemical molecules, can be effectively used to develop knowledge in relevant areas of the curriculum. Eleven studies in our survey investigated the impact of working with a computer simulation on content area knowledge. All 11 researched applications for the science curriculum, targeting, for example, knowledge of frog anatomy and morphology, thermodynamics, chemical structure and bonding, volume displacement, and health and disease. Students who worked with computer simulations significantly improved their performance on content-area tests (Akpan & Andre, 2000; Barnea & Dori, 1999; Geban et al.; Yildiz & Atkins, 1996). Working with computer simulations was in nearly every case as effective (Choi & Gennaro, 1987; Sherwood & Hasselbring, 1985/86) or more effective (Akpan & Andre, 2000; Barnea & Dori, 1999; Geban et al.; Huppert et al.; Lewis, Stern, & Linn, 1993; Woodward, Carnine, & Gersten, 1988) than traditional, hands-on materials for developing content knowledge.

Only two studies (Bourque & Carlson, 1987; Kinzer, Sherwood, & Loofbourrow, 1989) report an inferior outcome relative to traditional learning methods. Both studies failed to include a pretest, without which it is difficult to interpret posttest scores. Students in the simulation groups may have had lower posttest scores and still have made greater gains over the course of the experiment because they started out with less knowledge. Or they may have had more knowledge than their peers, resulting in a ceiling effect. Moreover, Bourque & Carlson (1997) designed their experiment in a way that may have confounded the computer simulation itself with other experimental variables. Students who worked off the computer took part in activities that were not parallel to those experienced by students working with computer simulations. Only students in the hands-on group were engaged in a follow-up tutorial and post-lab problem solving exercise.

Experimental flaws such as these are also problematic for many of the 11 studies that support the benefits of using computer simulations. Neither Choi & Gennaro (1987), Sherwood and

Hasselbring (1985/86), nor Woodward et al. included a pretest. Like Bourque & Carlson (1997, above) both Akpan & Andre (2000) and Barnea & Dori (1999) introduced confounding experimental variables by involving the computer simulation group in additional learning activities (filling out a keyword and definition worksheet and completing a self study, review and quiz booklet, respectively). In addition, four studies (Barnea & Dori, 1999; Huppert et al.; Woodward et al.; Yildiz & Atkins, 1996) did not clearly indicate that they randomized assignment, and two did not include a control group (Lewis et al.; Yildiz & Atkins, 1996). Little of the evidence to support computer simulations' promotion of content knowledge is iron clad. Although further study is important to repeat these findings, the quality of evidence is nevertheless on par with that supporting the use of traditional approaches. Taking this perspective, there is reasonably good support for the practice of using computer simulations as a supplement to or in place of traditional approaches for teaching content knowledge. However, the same questions mentioned above in talking about the skill development literature, linger here and need to be addressed in future research.

Factors Influencing Effectiveness

Factors influencing the effectiveness of computer simulations have not been extensively or systematically examined. Below we identify a number of likely candidates, and describe whatever preliminary evidence exists for their influence on successful learning outcomes.

Grade Level

At this point, it appears that computer simulations can be effectively implemented across a broad range of grade levels. Successful learning outcomes have been demonstrated for elementary (Berlin & White, 1986; Jiang & Potter, 1994; Kangassalo, 1994; Kinzer et al.; Park, 1993; Sherwood & Hasselbring, 1985/86; Vasu & Tyler, 1997; Willing, 1988), junior high (Akpan & Andre, 2000; Choi & Gennaro, 1987; Jackson, 1997; Jiang & Potter, 1994; Lewis et al.; Michael, 2001; Roberts & Blakeslee, 1996; Verzoni, 1995; Willing, 1988) and high school students (Barnea & Dori, 1999; Bourque & Carlson, 1987; Geban et al.; Huppert et al.; Jiang & Potter, 1994; Kelly, 1997-98; Mintz, 1993; Rivers & Vockell, 1987; Ronen & Eliahu, 1999; Willing, 1988; Woodward et al.; Yildiz & Atkins, 1996; Zietsman & Hewson, 1986). Because the majority of studies (14/27) have targeted junior high and high school populations, there is weightier support for these grade levels. But although fewer in numbers studies targeting students in grades 4 through 6 are also generally supportive of the benefits of using computer simulations. At this point, the early grades, 1-3 (Kangassalo, 1994) are too poorly represented in the research base to draw any conclusions about success of implementation.

Only one study has directly examined the impact of grade level on the effectiveness of using computer simulations. Berlin & White (1986) found no significant difference in the effectiveness of this approach for 2nd and 4th grade students. In the absence of other direct comparisons, a metaanalysis of existing research to determine the average effect size for different grade levels would help to determine whether this is a strong determinant of the effectiveness of computer simulations.

Student Characteristics

Looking across students, even just those considered to represent the "middle" of the distribution, there are considerable differences in their strengths, weaknesses, and preferences (Rose & Meyer, 2002). Characteristics at both the group and individual level have the potential to influence the impact of any learning approach. Educational group, prior experience, gender, and a whole variety of highly specific traits such as intrinsic motivation and cognitive operational stage are just a few examples. Although attention to such factors has been patchy at best, there is preliminary evidence to suggest that some of these characteristics may influence the success of using computer simulations.

With respect to educational group, the overwhelming majority of research studies have sampled subjects in the general population, making it difficult to determine whether educational group in any way influences the effectiveness of computer simulations. Only two studies (Willing, 1988; Woodward et al.) specifically mention the presence of students with special needs in their sample. Neither study gets directly at the question of whether educational group influences the effectiveness of computer simulations. However, they do make some interesting and important observations. Willing (1988) describes her sample of 222 students as being comprised mostly of students whom were considered average but in addition special education students, students with learning disabilities, and students who were gifted. Although Willing does not thoroughly address educational group in her presentation and analysis of the results, she does share a comment by one of the teachers that even less able readers seemed at ease reading when using the interactive historical text. Findings from Woodward et al. suggest not only that computer simulations can be effective for students with learning disabilities but that they may help to normalize these students' performance to that of more average-performing peers. Students with learning disabilities who worked with a computer simulation outperformed students without learning disabilities who did not receive any treatment. In contrast, untreated students without learning disabilities outperformed students without learning disabilities who took part in a control intervention consisting of conventional, teacher-driven activities.

Like educational group, gender is a factor sometimes associated with disparate achievement, particularly in math and science subject areas. In relation to the impact of computer simulations, however, it does not appear to be an important factor. Four studies in our review (Barnea & Dori, 1999; Berlin & White, 1986; Choi & Gennaro, 1987; Huppert et al.) directly examined the influence of gender on the outcome of working with computer simulations, and none demonstrated any robust relationship. In fact, a study by Choi & Gennaro (1987) suggests that when gender gaps in achievement exist, they persist during the use of computer simulations.
In contrast, there is evidence, although at this point isolated, that prior achievement can strongly influence the effectiveness of computer simulations. Yildiz & Atkins (1996) examined how prior achievement in science influences the outcome of working with different types of multimedia computer simulations. Students' prior achievement clearly affected the calculated effect size but how so depended on the type of computer simulation. These findings raise the possibility of very complex interactions between prior achievement and the type of computer simulation being used. They suggest that both factors may be essential for teachers to consider when weighing the potential benefits of implementing computer simulations.

Huppert et al. investigated whether students' cognitive stage might influence how much they profit from working with a computer simulation. Working with a computer simulation of microorganismal growth differentially affected students' development of content understanding and science process skill depending on their cognitive stage. Interestingly, those with the highest cognitive stage (formative) experienced little improvement from working with the simulation, whereas students at the concrete or transitional operational stages notably improved. Thus, reasoning ability may be another factor influencing the usefulness of a computer simulation to a particular student.

There are many more potentially important variables that have rarely been considered or even described in research studies. For example, only a small number of studies have specified whether subjects are experienced (Choi & Gennaro, 1987; Yildiz & Atkins, 1996) or not (Bourque & Carlson, 1987) with using computers in the classroom. None have directly examined this variable's impact. More thoroughly describing the characteristics of sample populations would be an important first step toward sorting out such potentially important factors.

Teacher Training and Support

Given the unevenness of teachers' technology preparedness, training and support in using computer simulations seems like a potentially key factor in the effectiveness of using computer simulations in the classroom. As it the case with many of the other variables we've mentioned, few studies have described with much clarity or detail the nature of teacher training and support. Exceptions are Rivers & Vockell (1987) and Vasu & Tyler (1997), both of whom give quite thorough descriptions of staff development and available resources. This is another area that merits further investigation.

Instructional Context

It has been suggested that combining computer simulation work with hands-on work may produce a better learning outcome than either method alone. Findings from Bourque & Carlson (1997) support this idea. They found that students performed best when they engaged in hands-on experimentation followed by computer simulation activities. However, Akpan & Andre (2000) report that students learned as much doing the simulated dissection as they did doing both the simulated and real dissection. This is an interesting question but one that will require additional research to squarely address.

Links to Learn More About Virtual Reality & Computer Simulations

Virtual Reality Society

http://www.vrs.org.uk/VR/reference/history.html

The Virtual Reality Society (VRS), founded in 1994 is an international group dedicated to the discussion and advancement of virtual reality and synthetic environments. Its activities include the publication of an international journal, the organization of special interest groups, conferences, seminars and tutorials. This web site contains a rich history of article listings and publications on Virtual Reality.

Virtual Reality and Education Laboratory

www.soe.ecu.edu/

This is the homepage of Virtual Reality and Education Laboratory at East Carolina University in Greenville, North Carolina. The Virtual Reality and Education Laboratory

(VREL) was created in 1992 to research virtual reality (VR) and its applications to the K-12 curriculum. Many projects are being conducted through VREL by researchers Veronica Pantelidis and Dr. Lawrence Auld. This web site provides links to VR in the Schools, an internationally referred journal distributed via the Internet. There are additional links to some VR sites recommended by these authors as exemplars and interesting sites.

Virtual Reality Resources for K-12 Education

http://archive.ncsa.uiuc.edu/people/bievenue/VR/

The NCSA Education & Outreach Group has compiled this web site containing links to multiple sites containing information and educational materials on Virtual Reality for Kindergarten through 12 grade classrooms.

Virtual Reality in Education: Learning in Virtual Reality

http://archive.ncsa.uiuc.edu/Edu/RSE/VR/

In collaboration with the National Center for Supercomputing Applications, the University of Illinois at Urbana-Champaign has created a five-year program to examine virtual reality (VR) in the classroom. One of the goals behind this program is to discover how well students can generalize their VR learning experiences outside of the classroom. This web site provides an explanation of the project with links to additional resources and Projects.

Human Interface Technology Laboratory, Washington Technology Center in Seattle

www.hitl.washington.edu/projects/knowledge_base/edvr/

This web site is the home of the Human Interface Technology Laboratory of the Washington Technology Center in Seattle, Washington. Various Virtual Reality (VR) articles and books are referenced. In addition to the list of articles and books, the technology center provides a list of internet resources including organizations that are doing research on VR, VR simulation environments and projects about various aspects of virtual reality.

Applied Computer Simulation Lab, Oregon Research Institute

www.ori.org/educationvr.html

This web site is from the Oregon Research Institute. The researchers at the Applied Computer Simulation Lab have created virtual reality (VR) programs that help physically disabled children operate motorized wheelchairs successfully. This website connects the reader to articles and information about these VR projects. Another project that this team is working on involves creating virtual reality programs for deaf blind students to help them "learn orientation and mobility skills in three dimensional acoustical spaces."

References

Ainge, D. J. (1996). Upper primary students constructing and exploring three dimensional shapes: A comparison of virtual reality with card nets. *Journal of Educational Computing Research, 14*(4), 345-369.

Ainge presents information from a study that involved students in grades five, six and seven. The experimental group contained twenty students and the control group contained eleven. The program was the VREAM Virtual Reality Development System which allows for easy construction of 3D shapes. Ease of using Virtual Reality (VR) and student engagement with VR were observed informally. VR had little impact on shape visualization and name writing, but enhanced recognition. Students had no difficulty in using the VREAM program and the student's enthusiasm for virtual reality was unanimous and sustained. The author cautions that the positive results from this study must be regarded as tentative because of the small number of participants.

Akpan, J. P., & Andre, T. (2000). Using a computer simulation before dissection to help students learn anatomy. *Journal of Computers in Mathematics and Science Teaching, 19*(3), 297-313.

Akpan and Andre examine the prior use of simulation of frog dissection in improving students' learning of frog anatomy and morphology. The study included 127 students ranging in age from 13-15 that were enrolled in a seventh-grade life science course in a middle school. The students had some experience in animal dissection, but no experience in the use of simulated dissection. There were four experimental conditions: simulation before dissection (SBD), dissection before simulation (DBS), simulation-only (S) or dissection only (DO). Students completed a pretest three weeks prior to the experiment and a posttest four days after the dissection was completed. Results of the study indicate that students receiving SBD and SO learned significantly more anatomy than students receiving DBS or DO. The authors suggest that computer-based simulations can offer a suitable cognitive environment in which students search for meaning, appreciate uncertainty and acquire responsibility for their own learning.

Barnea, N., & Dori, Y. J. (1999). High-school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *Journal of Science Education and Technology, 8*(4), 257-271.

The authors examined a new computerized molecular modeling (CMM) in teaching and learning chemistry for Israeli high schools. The study included three tenth grade experimental classes using the CMM approach and two other classes, who studied the same topic in a traditional approach, served as a control group. The authors investigated the effects of using molecular modeling on students' spatial ability, understanding of new concepts related to geometric and symbolic representations and students' perception of the model concept. In addition, each variable was examined for gender differences. Students in the experimental group performed better than control group students in all three performance areas. In most of the achievement and spatial ability tests no significant gender differences were found, but in some aspects of model perception and verbal argumentation differences existed. Teachers' and students' feedback on the CMM learning environment were found to be positive, as it helped them understand concepts in molecular geometry and bonding.

Berlin, D., & White, A. (1986). Computer simulations and the transition from concrete manipulation of objects to abstract thinking in elementary school mathematics. *School Science and Mathematics, 86*(6), 468-479.

In this article, the authors investigated the effects of combining interactive microcomputer simulations and concrete activities on the development of abstract thinking in elementary school mathematics. The students represented populations from two different socio-cultural backgrounds, including 57 black suburban students and 56 white rural students. There were three levels of treatment: (a) concrete-only activities, (b) combination of concrete and computer simulation activities, and (c) computer simulation-only activities. At the end of the treatment period, two paper-and-pencil instruments requiring reflective abstract thought were administered to all the participants. Results indicate that concrete and computer activities have different effects on children depending upon their socio-cultural background and gender. Learners do not react in the same way nor achieve equally well with different modes of learning activities. The authors suggest that mathematics' instruction should provide for the students' preferred mode of processing with extension and elaboration in an alternate mode of processing.

Bourque, D. R., & Carlson, G. R. (1987). Hands-on versus computer simulation methods in chemistry. *Journal of Chemical Education, 64*(3), 232-234.

Bourque and Carlson outline the results of a two-part study on computer-assisted simulation in chemical education. The study focused on examining and comparing the cognitive effectives of traditional hands-on laboratory exercise with a computer-simulated program on the same topic. In addition, the study sought to determine if coupling these two formats into a specific sequencing would provide optimum student learning. The participants were 51 students from general chemistry classes in high school and they worked microcomputers for the research activities. The students completed both a pretest and posttest. The results indicate that the hands-on experiment format followed by the computer-simulation format provided the highest cumulative scores for the examinations. The authors recommend using computer simulations as part of post laboratory activities in order to reinforce learning and support the learning process.

Bricken, M., & Byrne, C. M. (1992). Summer students in virtual reality: a pilot study on educational applications of virtual reality technology. Seattle, Washington: Washington University.

The goal of this study was to take a first step in evaluating the potential of virtual reality (VR) as a learning environment. The study took place at a technology-orientated summer day camp for students ages 5-18, where student activities center around hands-on exploration of new technology during one-week sessions. Information of 59 students was gathered during a 7-week period in order to evaluate VR in terms of students' behavior and opinions as they used VR to construct and explore their own virtual worlds. Results indicate that students demonstrated rapid comprehension of complex concepts and skills. They also reported fascination with the software and a high desire to use VR to build expression of their knowledge and imagination. The authors concluded that VR is a significantly compelling creative environment in which to teach and learn.

Brna, P. (1987). Confronting dynamics misconceptions. *Instructional Science, 16*, 351-379.

The authors discuss problems students have with learning about Newtonian dynamics and kinematics focusing on the assumption that learning is promoted through confronting students with their own misconceptions. Brna explains a computer-based modeling environment entitled DYNLAB and describes as a study with high school boys in Scotland employing it.

Choi, B., & Gennaro, E. (1987). The effectiveness of using computer simulated experiments on junior high students' understanding of the volume displacement concept. *Journal of Research in Science Teaching, 24*(6), 539-552.

Choi and Gennaro compared the effectiveness of microcomputer simulated experiences with that of parallel instruction involving hands-on laboratory experiences for teaching the concept of volume displacement to junior high students. They also assessed the differential effect on students' understanding of the volume displacement using student gender as an additional independent variable. The researchers also compared both treatment groups in degree of retention after 45 days. The participants included 128 students from eight-grade earth science classes. It was found that the computer-simulated experiences were as effective as hands-on laboratory experiences, and those males, having had hands-on laboratory experiences performed better on the posttest than females having had the hands-on laboratory experiences. There were no significant differences in performance when

comparing males with females using the computer simulation in the learning of the displacement concept. An ANOVA of the retention test scores revealed that males in both treatment conditions retained knowledge of volume displacement better than females.

Geban, O., Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem-solving approaches on high school students. *Journal of Educational Research, 86*(1), 5-10.

The purpose of this study was to investigate the effects of computer-simulated experiment (CSE) and the problem-solving approach on students' chemistry achievement, science process skills and attitudes toward chemistry at the high school level. The sample consisted of 200 ninth-grade students the treatment was carried out over nine weeks. Using the CSE, two experimental groups were compared as well as a control group employing a conventional approach. Four instruments were used in the study: Chemistry Achievement Test, Science Process Skill Test, Chemistry Attitude Scale, and Logical Thinking Ability Test. The results indicate that the computer-simulated experiment approach and the problem-solving approach produced significantly greater achievement in chemistry and science process skills than the conventional approach did. The CSE approach produced significantly more positive attitudes toward chemistry than the other two methods, with the conventional approach being the least effective.

Gorsky, P., & Finegold, M. (1992). Using computer simulations to restructure students' conceptions of force. *Journal of Computers in Mathematics and Science Teaching, 11*, 163-178.

Gorsky and Finegold report on the development and application of a series of computer programs which simulate the outcomes of students' perceptions regarding forces acting on objects at rest or in motion. The dissonance-based strategy for achieving conceptual change uses an arrow-based vector language to enable students to express their conceptual understanding.

Huppert, J., Lomask, S. M., & Lazarowitz, R. (2002). Computer simulations in the high school: Students' cognitive stages, science process skills and academic achievement in microbiology. *International Journal of Science Education, 24*(8), 803-821.

This study is based on a computer simulation program entitled: "The Growth Curve of Microorganisms," which required 181 tenth-grade biology students in Israel to use problem solving skills and simultaneously manipulate three independent in one simulated environment. The authors hoped to investigate the computer simulation's impact on students' academic achievement and on their mastery of science process skills in relation to cognitive stages. The results indicate that the concrete and transition operational students in the experimental group achieved higher academic achievement than their counterparts in the control group. Girls achieved equally with the boys in the experimental group. Students' academic achievement may indicate the potential impact a computer simulation program can have, enabling students with low reasoning abilities to cope successfully with learning concepts and principles in science that require high cognitive skills.

Jackson, D. F. (1997). Case studies of microcomputer and interactive video simulations in middle school earth science teaching. *Journal of Science Education and Technology, 6*(2), 127-141.

The author synthesizes the results of three cases studies of middle school classrooms in which computer and video materials were used to teach topics in earth and space science through interactive simulations. The cases included a range of middle school grade levels (sixth through eighth), teacher's levels of experience (student teacher through a 16-year veteran), levels of technology uses (interactive videodisk), and classroom organization pattern in relation to technological resources (teacher-centered presentations through small-group activities). The author was present in all class sessions and gathered data by performing teacher interviews, videotaping classes, taking interpretive field notes and copying the students' worksheets. In light of these findings, suggestions are made regarding improved design principles for such materials and how middle school science teachers might better conduct lessons using simulations.

Jiang, Z., & Potter, W. D. (1994). A computer microworld to introduce students to probability. *Journal of Computers in Mathematics and Science Teaching, 13*(2), 197-222.

The objective of this paper is to describe a simulation-orientated computer environment (CHANCE) for middle and high school students to learn introductory probability and a teacher experiment to evaluate its effectiveness. CHANCE is composed of five experimental sub-environments: Coins, Dice, Spinners, Thumbtack and Marbles. The authors desired detailed information from a small sample rather than a large sample so the participants included three boys (a fifth, sixth and eighth grader) and a girl (a junior). They were divided into two groups: Group 1 consisted of the younger students and Group 2 of the older. Each group worked with the investigator on a computer for two 1-hour sessions per week for five weeks. The results indicate that the teaching and learning activities carried out in the experimental environment provided by CHANCE were successful and supported the authors' belief that CHANCE has great potential in teaching and learning introductory probability. The authors caution generalizing these results, as there were only four students included in the study.

Johnson, A., Moher, T., Choo, Y., Lin, Y. J., & Kim, J. (2002). Augmenting elementary school education with VR. *IEEE Computer Graphics and Applications, March/April, 6-9.*

This article reviews a project in which ImmersaDesk applications have been employed in an elementary school for two years to determine if virtual environments (VEs) have helped children make sense of mathematics and scientific phenomenon. Since the beginning of the project, more than 425 students from grades K-6 have used the ImmersaDesk. The ImmersaDesk contains a 6-foot by 4-foot screen that allows 3-4 students to interact with each other while interacting with the VE on the screen. The positive feedback from the students and teachers indicate that VR can successfully augment scientific education as well as help to equalize the learning environment by engaging students in all ability levels.

Kangassalo, M. (1994). Children's independent exploration of a natural phenomenon by using a pictorial computer-based simulation. *Journal of Computing in Childhood Education, 5*(3/4), 285-297.

This paper is one part of an investigation whose aim was to examine to what extent the independent use of pictorial computer simulations of a natural phenomenon could be of help in the organizing of the phenomenon and the forming on an integrated picture of it. The author concentrated on describing children's exploration process, specifically 11 seven-year-old first-graders. The selected natural phenomenon was the variations in sunlight and the heat of the sum as experienced on earth related to the positions of the earth and the sun in space. The children were divided into four groups according to what kind of conceptual models they had before the use of the simulation. Children's conceptual models before the use of the simulation formed a basis from which the exploration of the phenomenon was activated. Children used the computer simulation over four weeks and each child differed as to the amount of operating time within each session (average of 65 minutes). The more developed and integrated their conceptual model, the more children's exploration contained investigating and experimenting with aim.

Kelly, P. R. (1997-98). Transfer of learning from a computer simulation as compared to a laboratory activity. *Journal of Educational Technology Systems, 26*(4), 345-351.

In this article, Kelly discusses the computer program he wrote that simulates a mineral identification activity in an Earth Science classroom. The research question was to determine if students who used the computer simulation could transfer their knowledge and perform as well on the New York State Regents Earth Science Exam as well as students who received instruction in a laboratory-based exercise. The results indicated no significant difference in the test scores of the two groups.

Kinzer, C. K., Sherwood, R. D., & Loofbourrow, M. C. (1989). Simulation software vs. expository text: a comparison of retention across two instructional tools. *Reading Research and Instruction, 28*(2), 41-49.

The authors examined the performance differences between two fifth grade classes. The first class was taught material about a food chain through a computer simulation and the second class was taught the same material by reading an expository text. The results indicated that the children in the second class, the expository text condition, did significantly better on the posttest than the students who received the information through a computer simulation program.

Lewis, E. L., Stern, J. L., & Linn, M. C. (1993). The effect of computer simulations on introductory thermodynamics understanding. *Educational Technology, 33*(1), 445-458.

The authors' purpose was to demonstrate the impact on eighth grade students' ability to generalize information about hydrodynamics learned through computer simulations to naturally-occurring problems. Five classes studied the reformulated Computer as Lab Partner (CLP) curriculum which makes naturally occurring events possible through computer simulation. The results indicate that the students understood the simulations and successfully integrated the hydrodynamic simulation information into real-world processes.

Michael, K. Y. (2001). The effect of a computer simulation activity versus a hands-on activity on product creativity in technology education. *Journal of Technology Education, 13*(1), 31-43.

The purpose of this study was to determine if computer simulated activities had a greater effect on product creativity than hands-on activity. Michael defined a creative product as "one that possesses some measure of both unusualness (originality) and usefulness." He hypothesized that there would be no difference in product creativity between the computer simulated group and the hands-on group. The subjects were seventh grade technology education students. The experimental group used Gryphon Bricks, a virtual environment that allows students to manipulate Lego-type bricks. The control group used Classic Lego Bricks. The Creative Product Semantic Scale (CPSS) was used to determine product creativity. The results indicated no differences between the two groups in regard to product creativity, originality, or usefulness.

Mintz, R. (1993). Computerized simulations as an inquiry tool. *School Science and Mathematics, 93*(2), 76-80.

The purpose of this study was determine if being exposed to computerized simulations expands and improves students' classroom inquiry work. The subjects in this study were fourteen and fifteen years old. The virtual environment consisted of a fish pond in which students had three consecutive assignments and a new variable was added to each assignment. The subjects asked to inquire hypotheses, conduct experiments, observe and record data and draw conclusions. As the experiments progressed, the students were able to answer questions using fewer simulation runs. The results support the author's hypothesis that exposure to computerized simulations can improve students' inquiry work.

Park, J. C. (1993). Time studies of fourth graders generating alternative solutions in a decision-making task using models and computer simulations. *Journal of Computing in Childhood Education, 4*(1), 57-76.

The purpose of this study was to determine whether the use of computer simulations had any affect on the time it took students to respond to a given task. The participants in this study were fourth graders who were split into four groups. They were given a decision-making task that required either hands-on manipulation of objects or computer simulated object manipulation. Three modifications of the computer simulation were implemented into the study. The first modification was computer simulation with keyboard input. The second modification was computer simulation with keyboard input and objects present for reference. The third modification was computer simulation with light input. Results indicated that students took longer to complete a task when they had to manipulate it using the computer simulation.

Rivers, R. H., & Vockell, E. (1987). Computer simulations to stimulate scientific problem solving. *Journal of Research in Science Teaching, 24*(5), 403-415.

The authors' purpose was to find if computerized science simulations could help students become better at scientific problem solving. There were two experimental groups: one that received guided discovery and the other group had unguided discovery. There was also a control group that received no simulations. The results indicated that the students in the guided discovery condition performed better than the unguided discovery and control groups.

Roberts, N., & Blakeslee, G. (1996). The dynamics of learning in a computer simulation environment. *Journal of Science Teacher Education, 7*(1) 41-58.

The authors conducted a pilot study in which they researched to better understand expert computer simulations in a Middle School Science classroom. In light of the focus on hands-on science instruction, the authors wanted to study this variable along with varying pedagogical instructional procedures. The study was conducted with 8 student participants of diverse abilities. The first half of the experiment time was in the science classroom in collaboration with the teacher. The second half of the study was conducted away from the classroom. The authors report three findings about computer simulations; (a) computer simulations can be used effectively for learning and concept development when teachers select pedagogical style based on learner needs versus student learning gains; (b) students learn more effectively when teachers directly teach students to build basic science knowledge and promote engagement; and (c) student learning is improved when teachers vary presentation style between direct instruction and student exploration. The authors conclude that in the area of computer simulation, hands-on experience is only one of several important variables in science learning.

Ronen, M., & Eliahu, M. (1999). Simulation as a home learning environment - students' views. *Journal of Computer Assisted Learning, 15*, 258-268.

The authors conducted a pilot study designed to research the possibility of integrating simulation-based activities into an existing homework structure during a 2 month period in a 9th grade setting. Students had simulation homework weekly which consisted of a 4-6 task assignment. Student views were collected using a questionnaire, personal student interviews, teacher interviews, and a final exam related to the content of the course. According to the authors, most students favored using simulations as a home learning process. They reported that this work was more stimulating, and the procedures enabled them to be more self-regulated learners. Teachers reported to be pleasantly surprised by the outcomes in student learning using the simulations, and realized reorganization of their physics instruction should occur to optimize the computer simulations. The authors conclude that the tool of computer simulations and others should be further explored.

Rose, D., & Meyer, A. (2002). Teaching Every Student in the Digital Age: Universal Design for Learning, ASCD.

This book is the first comprehensive presentation of the principles and applications of Universal Design for Learning (UDL)--a practical, research-based framework for responding to individual learning differences and a blueprint for the modern redesign of education. As a teacher in a typical classroom, there are two things you know for sure: Your students have widely divergent needs, skills, and interests; and you're responsible for helping every one attain the same high standards. This text lays the foundation of UDL, including neuroscience research on learner differences, the effective uses of new digital media in the classroom, and how insights about students who do not "fit the mold" can inform the creation of flexible curricula that help everyone learn more effectively. The second part of the book addresses practical applications of Universal Design for learning and how UDL principles can help you.

Schwienhorst, K. (2002). Why virtual, why environments? *Simulation and Gaming, 33* (2), 196-209.

This article was written to help clarify the definitions of Computer-Assisted Language Learning (CALL) and the Virtual Reality concepts and the support of each in learning. The manuscript includes a review of theoretical perspectives regarding learner autonomy including; individual-cognitive views of learning, the personal construct theory, and the experiential and experimental approaches to learning. The author notes the instructional benefits of virtual reality environments as learning tools which include greater self-awareness, support for interaction, and the enabling of real time collaboration. Finally, the author makes the call for experimental research in this area to verify the theory.

Sherwood, R. D., & Hasselbring. T. (1985/86). A comparison of student achievement across three methods of presentation of a computer-based science simulation. *Computers in the Schools, 2(*4), 43-50.

The authors report on the results of a study that focused on presentation methods of computer-base simulations in science. Specifically, three presentation methods were analyzed (a) computer simulations with pairs of students working on one computer, (b) computer simulation with an entire class, and (c) a game type simulation without a computer, all conditions were studied in classrooms of sixth grade students. Results indicate that there may be a small benefit to large group simulation experience, especially for immediate measures. These results imply that a computer for every student may not be necessary for students to benefit from computer "instruction" using simulations. The authors noted that student interest and some gender preferences might also influence performance in the simulation and effect measurement results.

Song, K., Han, B., & Yul Lee, W. (2000). *A virtual reality application for middle school geometry class.* Paper presented at the International Conference on Computers in Education/ International Conference on Computer-Assisted Instruction, Taipei, Taiwan.

Stratford, S. J. (1997). A review of computer-based model research in precollege science classroom. *Journal of Computers in Mathematics and Science Teaching, 16*(1), 3-23.

The author conducted a 10-year review of the literature on Computer-Based models and simulations in precollege science. Three main areas of Computer-Based Models were identified in the research; (a) preprogrammed simulations, (b) creating dynamic modeling environments, and (c) programming environments for simulations. Researchers noted that not enough empirical evidence was available to provide conclusive evidence about student performance. It was noted that anecdotal evidence supported high engagement in the computer-based models for most subjects. The author concluded by posing a number of future research studies, as this line of research is still in its infancy.

Sykes, W., & Reid, R. (1990). Virtual reality in schools: The ultimate educational technology. *THE Journal (Technological Horizons in Education), 27*(7), 61.

The authors conducted a pilot study in elementary and high school classrooms to study the use of virtual reality technology when used as an enhancement to the traditional curriculum. The major finding was that the engagement factor when using virtual reality enabled to students to be in a more active learning role. The authors argue that although most virtual reality applications in education are in science and mathematics at this time, the technology fits all curricula, and they see great potential across content and grade applications. Additional research should be conducted to validate these initial findings.

Taylor, W. (1997). *Student responses to their immersion in a virtual environment.* Paper presented at the Annual Meeting of the Educational Research Association, Chicago, Illinois.

The purpose of this study was to characterize students' responses to immersion in a virtual reality environment and their perceptions of this environment. Two thousand, eight hundred and seventy-two elementary, middle school, and high school students attended a thirty-minute presentation on virtual reality and then visited an immersive virtual environment. Following this virtual reality immersion, students answered a questionnaire, rating different facets of the experience. Questionnaire results suggest that although nearly every student enjoyed the experience of navigating a virtual environment such as this one, for many of them this task was quite difficult, and for some fairly disorienting. Results also suggested that the ability to see a virtual environment and navigate through it influences the environment's perceived authenticity. The authors suggest that future research be focused on technical improvements to virtual reality environments.

Vasu, E. S., & Tyler, D. K. (1997). A comparison of the critical thinking skills and spatial ability of fifth grade children using simulation software or Logo. *Journal of Computing in Childhood Education, 8*(4) 345-363.

The authors conducted a 3-group experimental study examining the effects of using Logo, or software using problem-solving simulations. The experimental groups were taught a 4-step problem solving approach. No significant differences were found on spatial or critical thinking skills until controlling for Logo mastery. With this control, significant differences were found for spatial scores, but not for critical thinking. The authors conclude that findings in such research take significant student learning and practice time. Additionally, teachers need substantial training to implant the program with success. The authors recommend further research to investigate further the power of simulation software.

Verzoni, K. A. (1995, October). *Creating simulations: Expressing life-situated relationships in terms of algebraic equations.* Paper presented at the Annual Meeting of the Northeastern Educational Research Association, Ellenville, NY.

Verzoni investigated the development of student's to see connections between mathematical equations and live like problem solving environments. Students were required to use cause and effect relationships using computer simulation software. Forty-nine eighth grade students participated in a quasi-experimental treatment/control study with a posttest only measure. The reported results suggest that simulation activities developed student abilities to make essential connections between algebraic expressions and real life relationships. The intervention occurred over 9 class periods. The author worked to capitalize on the concept of providing a purpose for algebraic work by having students create life like simulations, and appealing to the learner's own interests and background knowledge.

Willing, K. R. (1988). Computer simulations: Activating content reading. *Journal of Reading, 31*(5) 400-409.

The author capitalizes on the notion of student motivation and engagement in developing this descriptive study. Students ranging from elementary to high school age, and the range of abilities, students with identified disabilities to students noted as able and gifted (N=222) participated in this study. Willing focused on reading instruction while using computer simulation software in 9 classrooms for a three-week period. Teachers introduced and taught a unit using a simulation software programs. Students worked in groups of 2 to 6, as independent learning groups. Observations focused on type of reading (silent, coral, aloud, sub-vocally, and in turns), group discussions about the content, vocabulary development (use of terms and language specific to varying simulations), and outcome of the simulation (could the group help the simulation survive). The author concludes that these preliminary indicators favor the use of simulations to stimulate learner interest and cooperation to read and understand the content of the life like computer simulation.

Woodward, J., Carnine, D., & Gersten, R. (1988). Teaching problem solving through computer simulations. *American Educational Research Journal 25*, 1, 72-86.

The authors' purpose in this research was to study the effectiveness of computer simulations in content area instruction, in this case, health with 30 secondary students with high incidence disabilities. Participants were randomly assigned to one of two instructional groups, (a) teacher instruction with traditional practice/application practice, and (b) teacher instruction plus computer simulation. Health content was common across the groups for the 12 days of intervention. At the conclusion of the intervention, participants were tested on content facts, concepts and health-related problem solving issues. Results indicated a significant difference favoring the simulation group, with greatest difference in the problem-solving skills area. The authors recommend the combination of effective teaching and strategic instructional processes in combination with computer simulations for students to increase factual and higher order thinking skills.

Yair, Y., Mintz, R., & Litvak, S. (2001). 3-D virtual reality in science education: An implication for astronomy teaching. *Journal of Computers in Mathematics and Science Education 20*, 3, 293-301.

This study introduces the reader to the Virtual Environment. This report summarizes the use of this technology to reinforce the hypothesis that the experience in the three-dimensional space will increase learning and understanding of the solar system. With this technology, students are able to observe and manipulate inaccessible objects, variables, and processes in real-time. The ability to make what is abstract and intangible concrete and manipulabe enables the learner to study natural phenomena and abstract concepts. Thus, according to the authors, bridging a gap between the concrete world of nature and the abstract world of concepts and models can be accomplished with the Virtual Environment. Virtual Environments allow for powerful learning experiences to overcome the previously uni-dimensional view of the earth and space provided in texts, and maps.

Yildiz, R., & Atkins, M. (1996). The cognitive impact of multimedia simulations on 14 year old students. *British Journal of Educational Technology, 27*(2), 106-115.

The authors of this research designed a study to evaluate the effectiveness of three types of multimedia simulations (physical, procedural and process) when teaching the scientific concept of energy to high school students. The researchers attempted to design a study in which good experimental design was employed with 6 cells of students with a pre-post test design. The authors report that greater and more varied patterns of interaction were found for the procedural and process simulations versus the physical group. They conclude that variations in student characteristics and simulation type effect outcomes. However, the physical simulation was found to have produced greater cognitive gain than the other simulations. The authors also emphasize the need for further control and experimentation in this area.

Zietsman, A.I., & Hewson, P.W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 23*, 27-39.

The focus of this research was to determine the effects of instruction using microcomputer simulations and conceptual change strategies for 74 students in high school and freshmen year of college. The computer simulation program was designed based on the conceptual change model of learning. The author's report finding significant differences in pre to post measures for students receiving the simulations these students had more accurate conceptions of the construct of velocity. They conclude that science instruction that employs conceptual change strategies is effective especially when provided by the computer simulation.