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Virtual Reality/Computer Simulations and the Implications for UDL Implementation

Curriculum Enhancement Report

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Virtual Reality and Computer Simulations and the Implications for UDL Implementation: Curriculum Enhancements Report

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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 classroom. Educational researchers have turned their attention to these technologies, investigating the effectiveness of their curriculum application. This document examines this research and explores points of intersection with Universal Design for Learning (UDL), a curriculum design approach intended to lower the barriers that traditionally limit access to information and learning for many students. At this point of intersection are opportunities that could greatly expand teachers' capacity to support diverse learners. Computer simulations and virtual reality are potentially powerful learning technologies by themselves, offering teachers a means to concretize abstract concepts for students and provide them with opportunities to learn by doing what they might otherwise encounter only in a textbook. UDL provides a context for implementing these technologies and harnessing their power in a way that can improve learning experiences for every student in the classroom.

This discussion of virtual reality, computer simulations, and UDL begins with an introduction to these two technologies (presenting a definition and sampling of different types and a consideration of their curriculum applications) and a discussion of the research evidence for their effectiveness. In the second part of the paper the discussion turns to UDL applications of virtual reality and computer simulations. UDL is a theoretical approach that is based on research on the brain and effective teacher practices. This section develops an understanding of UDL and proceeds to identify ways that virtual reality and computer simulations support the approach at both the theoretical and teacher practice levels. The document concludes with general guidelines for UDL implementation and a list of Web resources that provide further information.

The literature review in this paper is also available as a stand-alone document, with annotated references. Look for it within the listing of Phase II Curriculum Enhancements Literature Reviews on the Enhancements Literature Review page of the National Center for Accessing the General Curriculum Web site http://www.cast.org/ncac/NCACPublications3117.cfm.

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 touch screen. 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) enables 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, and a virtual tour of an archeological site, and a recreation of the Constitutional Convention of 1787.

Applications Across Areas of the Curriculum

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).” This makes them a welcome alternative to the conventional study of science and mathematics, which requires 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 in addition to, for example, learning by 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., 2001).

Thus far 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 enables them to be integrated across 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, computer simulations and virtual environments are highly engaging, "There is simply no other way to engage students as virtual reality can (Sykes & Reid, 1999)." 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 as a Learning Enhancement

Before investing in a new technology or instructional approach it is important to know for certain that there will be a sizeable return on the investment. Research studies are designed to put instructional tools and instructional methods to the test, evaluating their effectiveness and exploring the conditions that impact their use (Figure 1). As such, research studies are an invaluable resource.

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. Students with special needs are not largely represented in the virtual reality/computer simulation evidence base, but an effort has been made to highlight research studies that are particularly relevant to special needs populations.

Questions that Research Studies Can Answer for Educators

What aspects of learning and achievement can this enhancement improve?
How big an effect does this enhancement have on learning and achievement?
How does the effectiveness of this enhancement compare to other approaches?
Is this enhancement effective for students with special needs?
Can this enhancement normalize the performance of students with special needs to that of other students?
For what grade level of student is this enhancement effective?
Are their gender differences in the impact this enhancement has on learning and achievement?
How much experience with an enhancement do students need in order to reap benefits from it?
Is this enhancement engaging for students?
What kind of instructional context(s) are best suited to this enhancement?
What classroom settings are best suited to this enhancement?
How much teacher training and support is needed to implement this enhancement effectively?
How long do the effects of working with this enhancement last?
Do the effects of working with this enhancement generalize to other situations?

Figure 1. A list of teacher-relevant questions that research studies can address for any enhancement.

Virtual Reality

Numerous commentaries and descriptions of virtual reality projects in education have been published. Research studies are still relatively rare. We identified three research investigations of virtual reality in the K-12 classroom, drawing from 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 highly 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., (2000) 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 (2000) 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., 2000).

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., 2000), 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. It will be important to establish that learning in virtual reality environments transfers to other contexts. At this point the evidence is promising, but 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.

The effectiveness of computer simulations for generating 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. Conceptual change in the science domain has been the primary target for such investigations, although we identified one study situated within the mathematics curriculum (Jiang & Potter, 1994). Each study we directly reviewed supported the potential of computer simulations to help accomplish needed conceptual change (see Table 1).

–TABLE 1–

Examples of Studies Using Computer Simulation to Promote Conceptual Change

Content	**Authors**	**Example topics of Conceptual Change**
Sciences	Zeitsman & Hewson (1986) Kangassalo (1994) Bryna (1987) Gorsky & Finegold (1992) White (1993) Stratford (1997)	• Relationship between velocity and distance • Dynamics
Mathematics	Jiang & Potter (1994)	• ***Probability***

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, although some of these studies have limitations with regard to research quality.

The effectiveness of computer simulations for developing skill. 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). 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). A variety of skills have been reported to be improved (Table 2).

– TABLE 2–

Effectiveness of Computer Simulations in Skill Development

Author(s)	Skills Improvement
Willing (1998)	Reading
Jiang & Potter (1994)	Mathematics problem solving
Rivers & Vokell (1987)	Mathematics problem solving
Verzoni (1995)	Algebra skills (relating equations to real situations)
Geban, Askar, & Ozkan (1992)	Science process skills
Huppert, Lomask, & Lazarowitz (2002)	Science process skills
Kelly (1997-8)	Mineral identification
Barnea & Dori (1999)	Three dimensional visualization
Berlin & White (1986)	Abstract thinking

Seven (Barnea & Dori, 1999; Berlin & White, 1986; Huppert et al., 2002; 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 seven studies suggest that computer simulations can be implemented to as good or better effect than existing approaches.

There are interpretive questions 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 such as a particular lesson sequence or a self-study booklet (Barnea & Dori, 1999; Geban et al., 1992; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997) that are not present or are different from those 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 are listed in Table 3 (Barnea & Dori, 1999;

Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997; Verzoni, 1995). When several of these flaws are present in the same study the findings should be weighted more lightly. Even excluding such studies, however, the evidence in support of computer simulations is still compelling.

–TABLE 3–

Design Flaws in the Skill Development Literature

Failure to control for instructional elements or supports present in the computer simulation intervention	Barnea & Dori, 1999; Geban et al., 1992; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997
Failure to randomize group assignment	Barnea & Dori , 1999; Kelly, 1997-98; Rivers & Vockell, 1987; Vasu & Tyler, 1997; Verzoni, 1995
Ill-documented, qualitative observations systems	Jiang & Potter, 1994; Mintz, 1993; Willing, 1988

Two studies reported no effect of computer simulation use on skill development (Mintz, 1993; Vasu & Tyler, 1997). 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. It is unclear whether they have a consistent advantage over other methods. Other 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.

The effectiveness of computer simulations for developing 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., 1992; 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., 1992; Huppert et al., 2002; 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.

The research suggests that computer simulations can effectively promote content knowledge, but little of the supporting evidence is iron clad (Table 4). Further study is important to repeat these findings and to address lingering questions such as the importance of teacher and staff training and how important novelty is to effectiveness.

–TABLE 4–

Experimental Design Flaws in the Content Area Knowledge Literature

Experimental Factor	Author(s)
No pretest measurement for pre and post treatment comparison	Bourque & Carlson, 1987; Kinzer, Sherwood & Loofbourrow, 1989; Choi and Gennaro 1987; Sherwood & Hasselbring, 1985/86; Woodward et al.1988
Confounding experimental variables	Bourque & Carlson, 1987; Akpan and Andre, 2000; Barnea and Dori, 1999
Failure to use random assignment	Barnea & Dori, 1999; Huppert et al, 2002; Woodward et al, 1988; Yildiz & Atkins, 1996
Absence of a control group	Lewis et al, 1993; Yildiz & Atkins, 1996

Factors Influencing Effectiveness

Factors influencing the effectiveness of computer simulations have not been extensively or systematically examined. Figure 2 contains a summary of potential factors and the relevant preliminary evidence gathered for this research report.

Effectiveness across Grade-levels

- Elementary – less evidence particularly at the primary levels (K-3)
- Junior High – considerable research evidence
- High School – considerable research evidence

Educational Groups

- Gender – differences noted in math and science abilities/ affect; no differences noted in use of computer simulations
- General education population has been most frequently sampled. The effectiveness of computer simulations for students with disabilities and students considered academically talented has been minimally sampled
- Prior achievement – appears to strongly influence effectiveness of computer simulation, particularly in science
- Cognitive stage (e.g., concrete to formative) – those students at highest stage less influenced by simulation experience

Teacher Training and Support

- Technology preparedness across studies uneven – potentially a key factor to fidelity of implementation

Instructional Context

- Context of simulation and hands-on experimentation, separate or combined – further research warranted

Figure 2. Factors that May Influence the Effectiveness of Computer Simulations

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., 1989; 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., 1993; Michael, 2001; Mokros & Tinker, 1987; Roberts & Blakeslee, 1996; Verzoni, 1995; Willing, 1988) and high school students (Barnea & Dori, 1999; Bourque & Carlson, 1987; Geban et al., 1992; Huppert et al., 2002; Jiang & Potter, 1994; Kelly, 1997-98; Mintz, 1993; Rivers & Vockell, 1987; Ronen & Eliahu, 1999; Willing, 1988; Woodward et al., 1988; Yildiz & Atkins, 1996; Zietsman & Hewson, 1986). The majority of studies have targeted junior high and high school populations, providing good evidence for effectiveness at these grade levels. Fewer studies have targeted students in grades 4 through 6, but these studies, too support the benefits of using computer simulations. The early grades, 1-3 (Kangassalo, 1994) are too poorly represented in the research base to draw any conclusions about success of implementation.

Student characteristics. 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 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., 1988) 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. These students read interactive texts that simulated historical events. Although Willing does not speak to differences in 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.

Subjects in the Woodward et al (1988) study included students with and without learning disabilities. Students with learning disabilities were assigned to one of two instructional groups in which they learned about nutrition and disease, the conventional group or the simulation group. Students in both of these groups received *structured teaching* at the beginning of each lesson. This involved teacher review of previous lessons and presentation of new vocabulary, followed by independent reading and responding to written comprehension questions. For students in the simulation group, follow-up activities took place in the resource room and consisted of teacher-mediated application and review activities. Students in the simulation group instead worked with a researcher and special education teacher in the computer lab, where they used health simulation software and an accompanying written curriculum to learn the same content. In contrast, the students without learning disabilities, who were enrolled in introductory or advanced health classes, received no treatment. On two follow-up tests students with learning disabilities in the simulation group outperformed their peers without learning disabilities. However students with learning disabilities in the conventional group performed below the level of their peers without learning disabilities. These findings 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.

Gender is a factor sometimes associated with disparate achievement, particularly in math and science subject areas. However, it does not appear to strongly influence the effectiveness of computer simulations. Four studies in our survey (Barnea & Dori, 1999; Berlin & White, 1986; Choi & Gennaro, 1987; Huppert et al., 2002) 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 and 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 (2002) 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 River and Vockell (1987) and Vasu and 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 the instructional context of combining computer simulation work with hands-on work may produce a better learning outcome than either method alone. Bourque and Carlson (1997) found that students performed best when they engaged in hands-on experimentation followed by computer simulation activities. However, Akpan and 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.

Summary

Virtual reality and computer simulations are technologies that have potential to positively impact learning by offering teachersand students a means to experience abstract concepts. The next section of this report introduces the reader to the theory and research behind UDL and investigates the links between UDL and virtual reality and computer simulations. Additionally, we identify methods and materials that support the implementation of virtual reality and computer simulations in concert with the principles of UDL. Finallywe present a set of guidelines for UDL implementation, including a listing of Web resources that provide further information on the content presented in this report.

An Introduction to Universal Design for Learning Applications

Universal Design for Learning is a theoretical framework developed by CAST to guide the development of curricula that are flexible and supportive of all students (Dolan & Hall, 2001; Meyer & Rose, 1998; Pisha & Coyne, 2001; Rose, 2001; Rose & Dolan, 2000; Rose & Meyer, 2000a, 2000b, 2002; Rose, Sethuraman, & Meo, 2000). The concept of UDL was inspired by the universal design movement in architecture. This movement calls for the design of structures that anticipate the needs of individuals with disabilities and accommodate these needs from the outset. Universally designed structures are indeed more usable by individuals with disabilities, but in addition they offer unforeseen benefits for all users. Curb cuts, for example, serve their intended use of facilitating the travel of those in wheelchairs, but they are also beneficial to

people pushing strollers, young children, and even the average walker. And so, the process of designing for individuals with disabilities has led to improved usability for others.
Similarly, but uniquely, UDL calls for the design of curricula with the needs of all students in mind, so that methods, materials, and assessment are usable by all. Traditional curricula present a host of barriers that limit students' access to information and learning. Of these, printed text is particularly notorious. In a traditional curriculum a student without a well-developed ability to see, decode, attend to, or comprehend printed text is compelled to adapt to its ubiquity as best as he or she can. In contrast, a UDL curriculum is designed to be innately flexible, enriched with multiple media so that alternatives can be accessed whenever appropriate. A UDL curriculum takes on the burden of adaptation so that the student doesn't have to, minimizing barriers and maximizing access to both information and learning.

The UDL framework guides the development of adaptable curricula by means of 3 principles (Figure 3). These 3 principles parallel 3 fundamentally important learning components and 3 distinct learning networks in the brain: recognition, strategy, and affect (Rose & Meyer, 2002). The common recommendation of these 3 principles is to select goals, methods, assessment and materials in a way that will minimize barriers and maximize flexibility. In this manner, the UDL framework structures the development of curricula that fully support every student's access, participation, and progress in all 3 essential facets of learning.

Principles of the Universal Design for Learning Framework
Principle 1: To support recognition learning, provide multiple, flexible methods of presentation **Principle 2:** To support strategic learning, provide multiple, flexible methods of expression and apprenticeship. **Principle 3:** To support affective learning, provide multiple, flexible options for engagement.

Figure 3. The three UDL principles call for flexibility in relation to three essential facets of learning, each one orchestrated by a distinct set of networks in the brain.

Critical to successfully implementing UDL theory is the use of digital materials. Digital materials, unlike the conventional pedagogical mainstays, speech, printed text, and printed images, have an inherent flexibility. They can be modified in a host of ways, depending on the needs of the student. This flexibility makes it feasible to customize learning materials and methods to each individual.

For teachers wondering *how* to customize the curriculum, CAST has devised three sets of broad teaching methods that support each of the 3 UDL principles (Figure 4, Rose & Meyer, 2002). These teaching methods draw on knowledge of the qualities of digital media and how recognition, strategic, and affective networks operate. For example, the first Teaching Method to support recognition learning is to *provide multiple examples.* This teaching method takes advantage of the fact that recognition networks can extract the defining features of a pattern and differentiate it from similar patterns simply by viewing multiple examples. Although presentation of multiple examples might be challenging in a classroom limited to printed text and hard copy images, digital materials enable the assembly, storage, and maintenance of a large collection of examples in the form of digital text, images, sound, or video – all in the modest space of a classroom. This is one example of how digital materials and UDL Teaching Methods can facilitate the successful implementation of UDL.

Network-Appropriate Teaching Methods
To support diverse recognition networks: • Provide multiple examples • Highlight critical features • Provide multiple media and formats • Support background context **To support diverse strategic networks:** • Provide flexible models of skilled performance • Provide opportunities to practice with supports • Provide ongoing, relevant feedback • Offer flexible opportunities for demonstrating skill **To support diverse affective networks:** • Offer choices of content and tools • Offer adjustable levels of challenge • Offer choices of rewards • Offer choices of learning context

Figure 4. To help teachers support learners' diverse recognition, strategic, and affective networks CAST has developed three sets of UDL teaching methods. These teaching methods can be used to make the curriculum more flexible and broadly supportive.

The UDL Teaching Methods will anchor the upcoming discussion where we will highlight the ways in which virtual reality and computer simulations align with each of the three UDL principles. Within the context of these teaching methods we'll show how virtual reality and computer simulations can support individualized instruction of recognition, strategic, and affective learning.

Virtual Reality/Computer Simulations and the Three Universal Design for Learning Principles

As digital materials, virtual reality and computer simulations have flexibility that suits them to the task of diversifying a curriculum in a UDL way. In each of the following sections, we discuss some specific ways that virtual reality and computer simulations can support curriculum diversification. The three UDL principles and their associated broad teaching methods (identified by italics) will set the context for this discussion.

Recognition learning. The first UDL principle recommends that we support recognition learning by providing multiple, flexible methods of presentation. No single teaching method can make every student an expert at recognizing patterns, but the right set of teaching methods can support every student's success. Virtual reality and computer simulations, as part of a diversified toolkit of classroom materials, can help curriculum designers and teachers achieve this end. They support all four UDL teaching methods for recognition learning.

One thing teachers can do to facilitate the recognition of patterns is to *provide multiple examples.* Text, speech, and image-based examples are an excellent start. The addition of computer simulations and virtual reality can help to further enrich a teacher's arsenal of examples. Even a single simulation or virtual reality environment can offer a multitude of examples within, and this increased exposure greatly expedites the learning of patterns by recognition networks.

Another route toward teaching patterns is to *highlight their critical features.* Virtual reality and computer simulations create some new possibilities for drawing attention to specific features, such as digitized pointers, highlighting, sound cues, and text captioning. In the case of virtual reality, features can be made to *pop out,* and/or digital *tour guides* can be programmed to point out important details. Best of all, these materials are flexible enough to permit the offering of a variety of highlighting methods, enabling each student to pick what is optimal for him or her.

Another powerful way in which computer simulations and virtual reality support a UDL approach to recognition learning is by helping teachers to *provide multiple media and formats.* Virtual reality and computer simulations incorporate multiple media into a single presentation, offering a rich, multi-sensory experience of a pattern. In this manner, they go well beyond what traditional media can do. They also are able to present these patterns in a three dimensional format. These features may help to create access to aspects of a pattern that may be difficult to communicate through traditional media. And they support students who struggle with printed text or speech.

The fourth broad UDL teaching method for recognition learning is to *support background knowledge.* Virtual reality and computer simulations can be mined as a tool to help students review background knowledge on a topic, priming their recognition networks for new knowledge. These digital environments not only provide a change of media for students seeking background information but also set up a situation where students can access various pieces of background knowledge as they see fit, ensuring that every student is supported at the appropriate level. Students may select from a range of computer simulations, depending on what they want to review. Similarly, students can flexibly access background information in a virtual environment. Perhaps they might tour a *virtual library,* pulling off the shelves only the materials that they find useful.

Strategic learning. The 2nd UDL principle asks that we support strategic learning by providing multiple, flexible methods of expression and apprenticeship. This principle and its associated teaching methods guide teachers in anticipating barriers to strategic learning and in selecting materials and practices that are flexible enough to overcome these barriers. These are tasks with which computer simulations and virtual reality are inherently compatible.

Generally, we learn well by example, but there are definitive individual differences. Different students may learn best from different examples, making it vital to provide students with *multiple models of skilled performance.* In a classroom short on digital materials, there are a very limited number of models for students to pick from because it is simply too hard to accumulate and store them when bound by printed text and images. And even the most generous set of models in printed text and printed images is limited in what information it can provide.

In contrast, digital environments such as computer simulations and virtual reality can provide students with rich, multi-sensory models, and it is relatively straightforward to offer students a very large number of such models to choose from. For example, a student learning to do an oral presentation could visit a virtual environment full of scientists, businessmen, poets, and politicians, and listen to a presentation by any or all of them. Computer simulations also make it easy to provide students with multiple models to choose from. A computer program could, for example, easily simulate multiple solutions to solving an algebra problem or to balancing the dynamics in a pond's food chain.

Of course, students also need opportunities to develop skills on their own. To be successful they need *opportunities to practice with supports.* Teachers need a way to simplify complex strategic patterns so that students can master individual subcomponents one by one. Computer simulations and virtual reality offer some unique means to accomplish this. Computer simulations can be presented at varying levels of complexity and are amenable to digitized supports such as notetaking features, links to resources, and tools such as automated graphing and unit conversion. With virtual reality, there are interesting possibilities such as programming helpers, tutors, and guides into the environment and simplifying the content of the environment or the potential routes through the environment.

As students practice skills it is important that teachers *provide ongoing, relevant feedback.* This is how students know whether they are succeeding and what tasks or skills may need continued work. Feedback provided during the course of learning is most effective (Rose & Dolan, 2000; Rose & Meyer, 2002). It enables students to incorporate feedback and make corrections while learning is still happening. Digital materials like computer simulations and virtual reality offer a relatively facile means to integrate ongoing feedback into practice and learning. Students can get immediate feedback from the program about their success. In addition, different types of feedback can be made available, helping to ensure the right fit to the student.

Without *flexible opportunities for demonstrating skill*, these skill-building supports would be of little use. Here, computer simulations and virtual reality offer some unique options. A student could construct a simulation to demonstrate his or her ability to apply algebra to real-life situations or to predict the outcome of a bacterial growth experiment or viral outbreak. Instead of writing a timeline of historical events, a student could demonstrate his or her ability to organize these events by navigating in proper order through a virtual historical environment. Computer simulations and virtual reality offer opportunities to demonstrate skill without some of the usual barriers. Consider, for example, the skill of identifying the parts of a frog's respiratory system. Traditionally, a teacher might have tested this skill by having a student dissect a frog, but for a student with a physical impairment or an allergy to formaldehyde this would be impossible. But these same students could demonstrate their skill in the context of a simulated dissection.

Affective learning. If students are not interested in what they are learning, efforts to support them in any of the above ways will have a much smaller return. This is why the third UDL principle recommends that we support affective learning by providing multiple, flexible options for engagement. Computer simulations and virtual reality can be important tools in ensuring that students across the board are engaging with learning.

The introduction of virtual reality and computer simulations into the classroom will greatly improve teachers' ability to *offer choices of content and tools* because their nature is so vastly different from those typically made available in the classroom. The non-print, interactive, multi-sensory, 3-dimensional, and in some cases hands-on nature of these tools can be highly engaging for students. Researchers Sykes and Reid have even said about virtual reality, "There is simply no other way to engage students as virtual reality can (Sykes & Reid, 1999)." These tools make certain types of content unusually accessible and enable students to work with that content in a way not normally possible. They can witness historical events and foreign cultures firsthand, manipulate objects in faraway galaxies, explore cause and effect on a shortened timescale, test complex principles of physics, and try out alternatives that might otherwise be too dangerous or difficult. Because computer simulations and virtual reality are programmed and digitized, it would be realistic for a teacher to offer students a selection of different environments and simulations with different content.

Another way to motivate students is to provide rewards. But no one kind of reward will motivate every student so teachers are encouraged to *offer a choice of rewards.* Computer simulations and virtual reality can help mix things up. It is not difficult to generate recreational forms of these materials that could be offered to students as an extrinsic reward for a job well done. In terms of intrinsic rewards, these materials are also valuable in terms of their ability to build students' sense of accomplishment by providing feedback and knowledge of results.

Students also benefit when teachers *offer a choice of learning context.* Factors like the degree of structure or support, the speed of the work, the level and timing of feedback, and the degree of game-like elements, are important to different students in different ways. With computer simulations and virtual reality teachers can vary some of these features and offer students enough choices that they can find a personally effective learning context.

Examples

In the above section, we have highlighted the many ways that computer simulations and virtual reality support the three UDL principles and align with UDL teaching practices. In this section, we go one step further, showing that this can work not only in theory but in practice as well. Here we present two actual lesson plans, one from CAST work, and one from outside work, that exemplify a UDL application of virtual reality or computer simulations. For the CAST example, we highlight the ways that computer simulations are used to implement UDL teaching methods. For the outside example, we identify general UDL features of the lesson and suggest ways that virtual reality or computer simulations could be additionally used to implement UDL and reduce lingering barriers.

CAST Model Spinner lesson from Planning for All Learners (PAL) toolkit. This lesson plan from CAST's PAL Toolkit addresses National Council of Teachers of Mathematics and Massachusetts Framework standards in mathematics by teaching students the relationship between theoretical and experimental probability. We encourage the reader to visit this CAST Web Site before or during their review of the table below. Whereas a traditional approach might use a text-based or mechanical spinner to teach students this relationship, for this UDL lesson students use a computer-simulated spinner from the Shodor Web site. The simulated spinner is flexible. Students can create a spinner with one to twelve sectors (each a different color), vary the number of spins, and view the theoretical and experimental probabilities both numerically and graphically. This flexibility fits right in with UDL. Table 5 lists the UDL features made possible by the use of this computer simulation.

–TABLE 5–

UDL Features of the CAST PAL Toolkit Model Spinner Lesson

UDL Teaching Method	Supportive Computer Simulation Feature(s)
Provide multiple examples.	Because the digital spinner can perform multiple trials in a very short time, multiple questions can be posed and answered quickly to illustrate multiple examples of the relationship between experimental and theoretical probability. In the large group setting students are able to view and discuss the results of multiple spinner configurations and multiple spins. Without the digital spinner, there are multiple instances of a particular event (e.g. coin flipping) but the RELATIONSHIP is only illustrated once in a very large number of trials.
Highlight critical features.	The digital format makes it possible for the teacher to highlight critical features of the spinner for the entire class using a projection plate. Students can also view a probability table and pie chart that highlight key features of the relationship between theoretical and experimental probability.
Provide multiple media and formats.	Theoretical and experimental probability are presented in multiple formats: a percentage table below the spinner and a pie chart showing the proportion of times that each sector is spun. The digital format of the spinner enables the use of text-to-speech.
Provide flexible models of skilled performance.	Because the spinner can be viewed and discussed by the whole class via projection plate, each student can observe the teacher and their peers modeling questioning and seeking data. Or students can work together at the computer in mixed ability groups. This means that lower achieving students can observe and participate with higher achieving students as they explore the relationships between the two types of probability.

Provide opportunities to practice with supports.	The spinner can be installed on multiple computers in the school – and at home – giving students ample opportunity to practice. The digital spinner offers supports such as the ability to simplify the spinner and text-to-speech compatibility. And it scaffolds the mechanical and calculation processes so that students can focus on the true purpose of the lesson.
Provide ongoing, relevant feedback.	Unlike mechanical tools like coins and dice, the digital spinner provides immediate feedback following each spin and feedback about large numbers of spins in an instant. This feedback is germane to the learning goal, understanding the relationship of theoretical to experimental probability.
Offer choices of content and tools.	Students can make a number of choices involving the spinner configuration, the type of data displays, and the number of spins.
Offer adjustable levels of challenge.	The adjustability of the spinner makes it possible to vary the difficulty level. With one to twelve sectors, students can work with a spinner whose complexity is appropriate to their level of understanding. In the group context, the complexity can be changed as the group gains understanding.
Offer choices of learning context.	Students can work with the spinner individually or view it with the whole class via a projection plate. Students can pursue the spinner activity on one of many computers at different times during the day. The spinner activity could also be taken home and installed on students' home computers, if available, or accessed via the web from home.

University of Washington Virtual Reality Roving Vehicles Program. This report describes a pilot study of the Virtual Reality Roving Vehicles program by University of Washington, which involved grade 7 students in the construction of virtual environments in the classroom. We encourage the reader to visit the Virtual Reality Roving Vehicles lesson Web site before or during their review of the table. In this pilot study students learned about wetlands ecology by a constructivist approach, where they self-reviewed information about a particular carbon cycle and then built a virtual wetland environment to demonstrate that cycle.

This instructional approach has several wonderful UDL features (see Table 6), most notably the use of multiple media, formats, and tools. A more comprehensive look at the UDL framework and teaching methods reveals ways to improve on this approach, further minimizing barriers and maximizing learning. In Table 7, we give some examples. Note that we are not offering generalized recommendations for making this lesson more UDL but instead are focusing on ways that virtual reality, in particular, can help achieve this goal.

–TABLE 6–

Existing UDL Elements of Virtual Reality Roving Vehicles Lesson

UDL Teaching Method	Supportive Lesson Feature(s)
Provide multiple media and formats.	Background materials are presented in a variety of media (including print, digital, and multimedia). Students work with multimedia when constructing their virtual worlds.
Support background context.	The teacher provides a variety of materials (including print, digital, and multimedia) about wetlands ecology and carbon cycles.
Provide opportunities to practice with supports.	Students work in groups to develop the virtual worlds. The web resources can be read with text-to-speech.
Offer flexible opportunities for demonstrating skill.	During world building students can work with both traditional and digital drawing and modeling tools.
Offer choices of content and tools.	Students can select materials from library guides and optionally review materials on the Internet, CD-ROMs, and video-disc.
Offer adjustable levels of challenge.	Students can select from a variety of resources the ones that present an appropriate degree of difficulty. Those for whom reading is too difficult can use text-to-speech as a scaffold.
Offer choices of learning context.	Students review background material on their own and work in groups on world building, enabling them to decide for themselves important aspects of the learning context.

–TABLE 7–

UDL Strategies to Further Minimize Lesson Barriers

Barrier	UDL Strategy
Incompatibility with assigned world building role	Enable students to select the world building role that is most effective and preferable to them.
World building	Provide models of virtual worlds at different stages of development; these could be made available on the computer. Provide ongoing feedback by having students post their work on the web for classroom peers and selected experts to see and comment on.
Student doesn't like drawing or struggles with it	Introduce other means to demonstrate skill and knowledge such as option of developing audio for the virtual world or text descriptions for those who cannot see.

Recommendations for Implementation at the Classroom Level

Although UDL applications of virtual reality and computer simulations already exist, they are admittedly hard to come by. Even with such models available, teachers face challenges in implementing them: the challenges of shifting away from traditional views of intelligence and traditional reliance on print media, the challenge of acquiring and mastering new technology, and the challenge of garnering support from the school system. The following sections offer recommendations that can help teachers overcome each one of these challenges.

Learn about universal design for learning. The first and most basic step toward successfully implementing UDL is self-education. Although UDL has been more than a decade in the making, it is a new approach and one that challenges many traditional educational perspectives and practices. Before teachers can implement UDL effectively, they may need to learn a different way of looking at their students and the materials that they use in the classroom. CAST has been working to disseminate UDL widely, and, consistent with the framework itself, has developed multiple avenues (direct and indirect, self-driven and trainer-taught, through text, speech, and interactive activities) through which individuals can learn about UDL and develop the skills necessary to put it into practice.

- Visit the CAST web site. The CAST Web site devotes a large section to Universal Design for Learning. Here visitors will find an articulation of UDL, discussions of its core concepts, descriptions of UDL research projects, a listing of tools and resources that support UDL, and ideas and examples for implementing UDL.

- Read CAST publications. CAST has a range of publications highlighting UDL and UDL practice, including Teaching Every Student in the Digital Age (Rose & Meyer, 2002). The companion Web site to the book provides an evolving set of resources and classroom examples, including interactive activities and an online community where visitors can ask questions and engage in discussion about UDL.

- Enroll in an institute. Professional development institutes by CAST teach professionals about the challenges of improving access to and progress and participation in the general education curriculum and how to make the curriculum accessible for all learners.

- Talk to others. The Teaching Every Student section of the CAST web site includes an online community where teachers can communicate, collaborate and obtain support from other educators who are exploring and teaching with UDL.

- Find more information and engage in discussion about universal design and increasing access for students with disabilities at the Web site for the Access Center, (www.k8accesscenter.org) a national technical assistance center that is funded by the U.S. Department of Education's Office of Special Education Programs make elementary and middle school curricula more accessible to students with disabilities.

Inventory and build technology support. Technology, in particular digital media, makes UDL implementation practical and achievable in a diverse classroom. Digital materials make it possible for the same material to be flexibly presented and accessed – even adapted on a student-to-student basis.

Although we recommend that teachers try to build a library digital of materials, it is important to point out that UDL implementation can proceed successfully across a range of technology availability. The amount of technology available to teachers varies extensively – limited by district and school resources, both monetary and otherwise. Fortunately, a fairly simple step such as digitizing print materials can greatly ease UDL implementation. The 1996 United States copyright additions (Chapter 1 of Title 17 Section 121 of the United States Code) the Chafee Amendment, gives authorized entities the freedom to digitize otherwise proprietary materials for individuals that have disabilities that impede access to the printed version. An authorized entity is a nonprofit organization or governmental agency that has a primary mission to provide specialized services relating to training, education, or adaptive reading or information access needs of blind or other persons with disabilities. This provision makes special education teachers eligible to digitize printed text materials, a step that can help to diversify the presentation of materials for students with disabilities.

Another inexpensive but instrumental option for supplying a classroom with digital materials is the World Wide Web – a tremendous source of free digital material. And much of this material is in a multimedia format, which can greatly improve access to students.

Having more digital media unquestionably enables teachers to implement UDL in a more extensive way. Teachers who have greater financial resources and district support can supplement their materials with innovative products such as multimedia composition tools (e.g. HyperStudio, Kid Pix, PowerPoint), graphic organizer software (e.g. Inspiration, Kidspiration), text-to-speech and text-to-image programs (e.g. CAST eReader, Pix Reader, Pix Writer, Intellitalk II), CD-ROM storybooks (e.g. Reader Rabbit's Reading Development Library), and learning software (e.g. 7th Level's Great Math Adventure, Edmark's various learning games).

Whether teachers are able to invest in the purchase of a lot of technology or not, UDL can proceed effectively. But taking inventory is an important step toward setting a realistic course of action. By inventorying the resources they have available to them, teachers can determine the level of UDL implementation appropriate to their classroom. For example, visit the school media center and get an idea of computer and projection systems available to teachers and students. Find out if these tools are portable or fixed, this implies where instruction may take place. Check into scheduling issues around shared equipment. Additionally, check out web accessibility in classrooms, school computer labs and media centers. If the web is a tool you may use and ask students to access, how available is it? Additionally, take an inventory of your school or district software, find out what's available and if the purchase permits installation on computers you will be using.

Effectively working with and managing technology can be a challenging process, so it is important as well to inventory the available technology support. This may come in the form of a technology specialist (computer teacher, computer resource specialist, technology integration teacher) or one's own technology training. Find out what policies your school or district may have regarding the tools you may adopt for use in your planning and teaching. Installation of software and hardware on computers may be time consuming, plan for issues of timing in your implementation. When you are ready to teach a lesson using some technologies new to you or your students, consider notifying your technology support person, to be at hand to help problem solve any unforeseen challenges with implementation.

Curriculum planning and delivery. Another important step in implementation of UDL in instruction is curriculum planning and delivery. To begin with we recommend that teachers have a basic understanding of Universal Design for Learning, and a commitment to make the curriculum and learning accessible for all learners. While keeping in mind the three principles of UDL, based on the three networks recognition, strategic and affective, we have found the following process useful in designing lessons. The process includes four steps, based upon the principles and concepts of UDL, proven professional development strategies, and effective teaching practices; (a) Set Goals, (b) Analyze Status, (c) Apply UDL, and (d) Teach the UDL Lesson.

> In the *Set Goals* stage of curriculum planning, we recommend that teachers establish the context for instruction. Context is usually driven or based on state standards, followed by the design of goals for the instructional episode. We recommend that all teachers closely evaluate these to assure alignment and assure that the means for attaining the goals are separated from the goals and standards.
>
> Next, when designing a UDL lesson, teachers should *Analyze the Current Status* of the instructional episode. What are the current methodologies, assessments, and materials used to teach the lesson? Analyze these teaching procedures in relation to potential barriers of learners in the classroom. Do all students have access to the materials? Are students able to express themselves with the current methods and materials? There are a number of resources and tools available from CAST to analyze lessons in the Planning for All Learners Toolkit located on the TES web site.
>
> The third recommended step of the planning process is to *Apply UDL to the Lesson/Unit*. This includes the goals, methods, assessments and materials used to implement the lesson. Create the UDL lesson plan, grounded in the learning goals, classroom profile, methods and assessment, and materials and tools. Then, collect and organize materials that support the UDL lesson.
>
> In the final step, *Teach the UDL Lesson/Unit*, minimize barriers and realize the strengths and challenges each student brings to learning, rely on effective teaching

practices, and apply challenges appropriate for each learner. In this way, instructors can engage more students and help all students progress. When teaching and evaluating students' work, also evaluate and revise the lesson/unit to assure student access and success. You may obtain additional information about designing UDL methods, assessments, and materials, in Teaching Every Student in the Digital Age, Chapter 4.

Secure administrative support. School districts and administrations can be powerful sources of support – financial and otherwise. Administrative commitment to UDL can strengthen a teacher's sense of mission and self-satisfaction and lead to important funding. A case in point is the town of Gloucester, Massachusetts. The principal for the school system is so convinced of the importance of digitized materials that he has set a mandate that when selecting new texts, teachers use only those textbooks that have a digitized version accompanying the book. Teachers and students have text-to-speech readers available to further improve the accessibility of the text. Clearly, this kind of change would have happened much more slowly in the absence of such tremendous administrator-level support.

Administrator support can also help to facilitate funding, which although not a prerequisite for UDL, can create important opportunities. Funding might enable the purchase of equipment, professional development, and the launching of new UDL teaching projects. Districts vary widely concerning the types and level of funding that they offer teachers, but teachers who can convince their administrators of the value of UDL may be able secure district-level grants, professional development awards, and sabbaticals. For example, in a North Shore Massachusetts school district, the Technology Program Manager and Special Education Director teamed with two teachers using UDL wrote and were recently awarded a state-level technology grant to implement UDL. This is just one example of how support at the administrative level can facilitate the acquisition of materials that support UDL efforts in the classroom.

Parent education and involvement. Parents are another valuable resource for teachers building a UDL curriculum. There are at least two important ways that parents can be a resource: as advocates and as volunteers.

By educating parents about the UDL activities going on in the classroom, teachers can develop a support system of informed individuals who can assist with and advocate for UDL instruction. Teachers should think about ways to inform parents about classroom activities. Notes sent home, parent night presentations, and IEP meetings are all excellent opportunities to engage in this kind of communication.

Once parents are educated about UDL they may wish to become involved themselves. There are many ways that parents can do this, including volunteering in the classroom and lending support at home. A few possibilities are scanning materials, monitoring kids during UDL lessons, helping with technology, donating equipment, and supporting homework assignments.

Conclusion

Virtual reality and computer simulations, although still new and developing technologies, have the potential to deliver great benefits in the classroom. One of their greatest areas of potential is in supporting UDL and its efforts to generate more flexible and broadly accessible curricula. Indeed, UDL and new technologies such as virtual reality and computer simulations are mutually supportive. Together they are a strong lever for other kinds of education reform, "Instead of being 'just one more thing,' the UDL framework provides a way to make various approaches to educational change more feasible by incorporating new insights on learning and new applications of technology (Rose & Meyer, 2002, p. 8).” As virtual reality and computer simulations continue to evolve and the relevant research base grows, they will be a worthwhile focus of attention for UDL researchers, UDL teachers, and all proponents of education reform.

Links to Learn More About Virtual Reality and Computer Simulations

Virtual Reality Society Web site

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

This page on the “World of VR” web site provides a timeline documenting the history of virtual reality.

Education World Web site

www.education-world.com/a_tech/tech010.shtml

This article from Education World focuses on MOO – multi-user, object-oriented environments. The article includes links for educators to learn more about ways in which students in the classroom are using MOO.

East Carolina University Virtual Reality and Education Laboratory Web site

www.soe.ecu.edu/vr/vrel.htm

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. VREL researchers Veronica Pantelidis and Dr. Lawrence Auld are conducting numerous research projects. 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 web pages recommended by the authors as interesting sites or exemplars.

University of Illinois National Center for Supercomputing Applications Web site

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 projects and online virtual reality resources for K-12 education.

The Washington Technology Center Human Interface Technology Laboratory Web site

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. On this site the Center references various Virtual Reality (VR) articles and books. In addition, it provides a list of Internet resources, including organizations that are doing research on VR, VR simulation environments, and projects about various aspects of VR.

Oregon Research Institute Applied Computer Simulation Lab

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."

The Access Center

http://www.k8accesscenter.org/

This Web site belongs to the Access Center, a national technical assistance center, funded by the U.S. Department of Education's Office of Special Education Programs. The purpose of the K12 Access Center is to make elementary and middle school curricula more accessible to students with disabilities. The Web site hosts chats and discussions and offers publications and presentations on topics related to accessing the general education curriculum, including Universal Design for Learning.

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