USING INTERACTIVE MULTIMEDIA TECHNOLOGIES TO IMPROVE STUDENT UNDERSTANDING OF SPATIALLY-DEPENDENT ENGINEERING CONCEPTS

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Abstract

Interactive multimedia provides a unique avenue for the communication of engineering concepts. Although most engineering materials today are paper-based, more and more educators are examining ways to implement publisher-generated materials or custom, self-developed digital utilities into their curricula. It is vital that engineering educators continue to integrate digital tools into their classrooms because they provide unique avenues for active student learning opportunities and describe engineering content in a way that is not possible with traditional methods. This contribution discusses the importance of spatial ability in engineering curricula and describes an interactive multimedia application that was designed to better communicate spatially based materials science and engineering concepts to students.

Keywords: human-computer interface; improving classroom teaching; interactive learning environments; multimedia/hypermedia systems; virtual reality.

INTRODUCTION

In a 1986 survey of professional engineers in educational and industrial settings, Jensen found that spatial ability is the most important aptitude that an individual should posses to be successful in the engineering profession. Obtaining even a basic understanding of the rudimentary concepts from any number of engineering specialties requires some measure of spatial visualization and orientation abilities. As one advances, spatial ability becomes more and more important. During this advancement, spatial ability must be developed and refined to comprehend and decipher more complex spatially related information. From visualizing data structures communicated by abstract symbolic systems to understanding the interaction of tangible mechanical parts portrayed through schematic drawings, spatial cognition in its various forms is a highly coveted skill throughout one's career progression.

Indeed, spatial ability is not only an important skill for engineers, but also for a wide variety of other disciplines as well. For example, as reported by Bertoline (1988) spatial ability is important for success in biology (Lord, 1985), chemistry (Talley, 1973), mathematics (Macoby & Jacklin, 1974), and science (Small & Morton, 1985). Additional studies collected from diverse journals in astronomy (Bishop, 1978), chemistry (Coleman & Gotch, 1998; Khoo & Koh, 1998; Baker & Talley, 1972), biology (Lord & Nicely, 1997), engineering (Miller, 1996), geology (Yakemanskaya, 1971), music (Hassler, Birbaumer, & Feil, 1985), mathematics (Kiser, 1990; Sherman, 1967; Smith, 1964), and physics (Anderson, 1976; Pallrand & Seeber, 1984) also support this view. That a wide range of research concerning spatial ability exists is no question. Although the intricacies of identifying, measuring and improving spatial ability are often debated, it can be confidently stated and agreed that without developed spatial abilities students are often hindered in the learning environment and ultimately within their chosen field (Bertoline, Burton, & Wiley, 1992).

Even though spatial ability is certainly important for engineers, many engineering curricula devote little or no time in the advancement of it. Bertoline (1987) notes that students are frequently given little or no formal instruction in the use and development of spatial abilities. More recently, Mathewson (1999) also comments that educators commonly neglect teaching visual-spatial thinking. An examination of most paper-based materials reveals that they do little to foster developmental growth of spatial abilities. Engineering texts frequently present orthogonal, static views of concepts, theories and ideas with little or no explanation or focus on interpreting the spatial data. Almost all assume that the student will be able to make the mental leap, piecing together the spatial puzzle.

Yet, if one of the goals of engineering education is to successfully prepare individuals for various engineering professions, and if spatial ability is a part of successful preparation and future advancement, instructional approaches should be developed that allow students to augment and advance their spatial abilities relative to the specifics of the chosen engineering specialty. If students are not given an opportunity to develop and enhance their spatial abilities through educational experiences using the latest technologies such as interactive multimedia or web-based resources, they may abandon their quest to become engineers or fail to achieve their full potential as practicing engineers (Bertoline, et. al., 1992). Thus it is imperative that engineering educators quickly begin examining, testing and implementing interactive multimedia and web technologies where practically and justifiably valid.

METHODS FOR IMPROVING SPATIAL ABILITY

With the acknowledgement that spatial ability is important, it is meaningful to identify the primary methods that have been used to increase the spatial abilities of engineering students and their understanding of engineering concepts. Much of the literature and research focuses on issues surrounding group and individual differences related to a number of dependent variables, such as gender, cultural background, and other environmental characteristics. At present, however, more and more studies are aimed at discovering appropriate technologies and apposite techniques that can be used with relative confidence. Researchers are beginning to examine the validity and reliability of CD-ROM and web-based technologies to communicate scientific and engineering content. As the technology concurrently impacts engineering education, computer-based multimedia is also increasing in the larger context of education. Various cause and effect relationships are being studied as to the reason multimedia instruction is successful in this larger scope (Bagui, 1998; Najjar, 1996). Nevertheless, it is no surprise that increased efforts are being pursued in specific disciplines such as engineering education.

Historically, while not having a primary focus within the engineering curriculum, researchers in engineering disciplines have nevertheless tested numerous methods in an attempt to teach and further spatial abilities of engineering students, each with varying levels of success. Traditional paper and pencil (Dejong, 1977; Newlin, 1979), real models (Wiley, 1989; Wiley, 1990; Miller, 1992a), 2D CAD (Mack, 1995; Mack, 1994), 3D CAD (Devon, Engle, Foster, Sathianathan & Turner, 1994; Braukmann & Pedras, 1993; Miller, 1992b; Leach, 1992; Vanderwall, 1981), 3D animation (McCuistion, 1990; Weibe, 1993) and computer games (Dorval & Pepin, 1986) have all been used in an attempt to improve student spatial abilities. Although not an exhaustive list of approaches or studies, an increase in the capabilities of the desktop computer has dramatically multiplied the various strategies that can be employed and time it takes to establish such as system.

There are now many computer-based tools that are well suited for visualization instruction and remediation relative to specific engineering specialities. The desktop computer provides an excellent environment that allows for development and delivery of both static and dynamic media much more readily than in the past (Wiebe, 1993; Anglin, Towers & Moore, 1997; Park, 1998). The computer can easily become an extension of the mind, allowing the student to view their cognitive processes. Frequently, the computer monitor becomes both a looking glass and a tutor for mental processes that are often difficult to identify and analyse with traditional instructional methods.

Yet, it must be noted that the complexity of some environments and the overload of the human senses can add to the cognitive workload required of a student, consequently becoming a barrier to the honing of visualization skills, or for that matter, any cognitive ability tutored via the computer (Metallinos, 1994). In any computer-based environment, the mental focus should not be upon the digital tool or on how information is accessed. Rather, emphasis should be placed upon exercising visual abilities or the skills one wishes the student to acquire. Frequently digital tools can become a hindrance to learning, particularly upon first exposure. As it relates to environments for visualization, suitably designed digital tools must provide affordances and conceptual clues that allow the student some relationship or correlation to the real world so that they may easily operate within the environment (Gibson, 1986). When a computer is used, ultimately students must understand the environment and the methods for controlling it. Additionally those control mechanisms should be as transparent as possible, allowing the student to focus on the material at hand.

MULTIMEDIA & ENGINEERING EDUCATION

Although personal definitions abound, generally it is accepted that multimedia is classified as any combination of text, graphics, sound, animation, and video delivered and controlled by the computer (Vaughn, 1993). Extending this definition, interactive multimedia is defined as non-linear multimedia, that is, any tool that gives control to the user rather than the computer. This shift of control allows for individually customized information flow (Park, 1994). These applications centre on the user through menu-driven programs, hypermedia applications, process simulations, performance dependent programs, direct-manipulation environments or combinations of these interactive techniques (Wolfgram, 1994).

In general, multimedia has been relatively successful because it draws upon more than one of the five human senses, utilizing the two fundamental senses vital for information reception – sight and sound. Due to motion and sound, it can also spark attention, interest and motivation in the process. However, multimedia alone is intriguing at best and does not require the user to be actively controlling or necessarily thinking about what is being presented (Burger, 1993). Such tools simply run in a linear progression with no input from the user; a possible explanation for the lack of attentiveness apparent in students who are taught via linear videos or slide-based self study modules. Today, sight and sound is not enough to guarantee that students will learn from educational materials. One must then inquire, “What, then, is the critical component of learning digital learning materials?”

Planned interactions are known to have a very positive effect on learning and these are likely the most critical component of any learning environment, particularly computer-based ones. Whether interaction comes from teacher, peers, or the learning materials themselves, it is the interaction and the level to which that interaction is unique that results in learning. Learning theorists state that to reach an objective or to acquire a skill, the learner must be actively involved through practice to cognitively incorporate it into long-term memory. The interaction or “doing the objective” helps the learner reach the objective and recall the information, skill, or behaviour that was learned (Dick & Carey, 1992).

Coinciding with this, Wolfgram (1994) states, "People only remember 15 percent of what they hear and 25 percent of what they see, but they remember 60 percent of what they interact with” (p.12). Multimedia, as well as any environment in which there is little or no interaction, can fall quite short for learning. However, interactive multimedia supersedes linear multimedia techniques by requiring internal user processing and focusing on the needs of the user; thereby requiring the user to be actively thinking about the information being presented, making predetermined decisions, and presumably, acquiring the information or skills desired. By drawing upon multiple human senses and requiring human interaction, the learner acquires knowledge more efficiently. Thus, interactive multimedia is a powerful medium for education and training. It is also a very adaptive tool in marketing situations where a persuasive flair helps change an attitude or belief (Stephanae, 1994).

The sole limiting factor of paper-based materials is that they provide a calloused or distant means of user interaction with the information being presented. They also give a shallow and somewhat blurred view of intended meaning since they utilize only one human sense through obscure characters and motionless graphics, which often interferes with both transfer and retention. This type of media, also known as "monomedia" (Lindstrom, 1994), has low aesthetic value due to the static nature of the printed page. It presents a monotonous world to humans who are multimedia communicators – desiring motion and sound – and who thrive on interaction. Similarly with the mass of information that must be found, examined, consumed and retained by today’s engineering students, it is questionable whether traditional presentations and traditional learning materials are the most efficient means to obtain critical information.

Although engineering content lends itself well to interactive multimedia techniques for delivery, most materials are still traditionally based. Thus they lack user interaction and are hindered by low sensory attractiveness. This is especially true of traditional classroom presentations delivered to today’s college students. These students have grown up in the information age and are easily bored with traditional presentations. They may “turn off” traditional presentations and not grasp an important concept just because they become disenchanted with the method of presentation. Thus, engineering educators must begin to utilize interactive multimedia more broadly in their curriculum materials. Although interactive multimedia use is increasing, the rate of student expectations for technology integration has exceeded the rate of instructor implementation within the classroom. Instructors must proactively find, review, evaluate and implement interactive technologies within the classroom – when such materials are found to be reliable, valid, and therefore valuable.

VIRTUAL REALITY AND SPATIAL VISUALIZATION

One of the most promising multimedia technologies for engineering education is virtual reality (VR). One of the detriments of other computer-based strategies is that the student is often distanced from the environment or objects, particularly as it relates to static images or animations. The advantage of VR technology is that it allows people to expand their perception of the real world in ways that were previously impossible (McLellan, 1998). As McLellan states, "VR is a cognitive tool that allows dynamic and immediate interaction" as well as "emersion." The interactivity inherent to VR is aimed at extending and enhancing human cognitive abilities. Thus, it provides a superb vehicle for enhancing and possibly improving student understanding of engineering concepts that are spatially dependent.

However, it must be noted that the perception of VR technology often portrayed by the media through movies and other sources reveals a photo realistic environment, flawless in its representation of reality. However, the desktop application of VR is far from the complete and perfect representation of the real world. Several technical limitations prevent the real-time display of completely realistic environments with total submersion on the desktop. Tremendous processing requirements, high data rates, and expensive display technologies limit the amount of realism that can be provided. Although considerable research in hardware and software development is taking place, technology has not advanced to a stage that can provide the "real world" on the desktop.

Yet, the purpose of VR is not to provide the complete and exact representation of the real world on the computer, although someday desktop-computing power, attainable by the masses, may allow it. Today, VR is about experience and interaction, not the simulation of true reality. Thus for educational situations, the level of realism provided by today's VR systems and applications is adequate for the communication of engineering concepts and may readily provide a means for engaging students in active learning situations.

To determine the level of complexity of VR systems, several researchers are developing scales by which these systems can be measured and compared. Thurman and Mattoon (1994) presented a model that classifies VR based on three dimensions: verity, integration, and interface. The verity dimension attempts to describe the level at which the environment or the objects represent true reality. The integration dimension describes how the user is integrated and/or represented in the environment, and the interface dimension describes how the user interacts with the environment.

Today, an environment that provides the maximum in all three dimensions has not been developed. However, several technologies show promise in reaching the maximum. Proprietary technologies and non-proprietary technologies, such as VRML, provide a means for creating virtual worlds. Yet, these technologies have significant technical limitations and are far from reaching the highest rating for verity, integration, or interface. Most of the proprietary programs do provide high quality virtual environments (high verity). In spite of that they are often far more costly than most educational institutions can afford due to the processing power needed and the expense of input and output devices. This is particularly true where multi-workstation laboratory configurations are concerned. VRML, which is far more cost effective, provides a lack of realism (low verity) and requires significant bandwidth considerations for delivery. Additionally, the interface dimension of these tools is often difficult to use and control. Thus, the tool has a tendency to get in the way of communication.

Although both these technologies provide true three-dimensional environments a third evolving technology, video-based VR, provides promise as it is significantly less expensive to create, easier to deliver, and provides photo realistic content. Due to the fact that it is a video-based technology, it is not based upon the real-time delivery of three-dimensional data. Rather, it is composed of snapshots of predefined views that give the illusion of navigation within a three-dimensional environment or manipulation of a three-dimensional object.

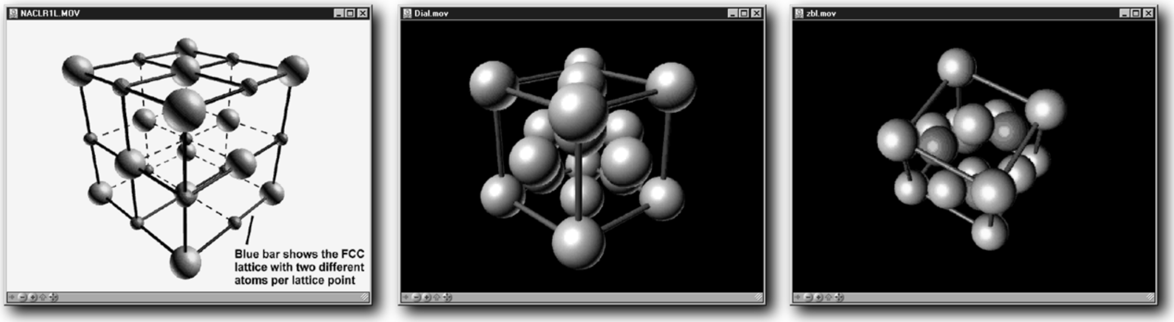
Because video-based VR is based upon predefined views, educators who use it can control the path of motion through an environment or the translation and rotation of an object. Educators have complete control over the pedagogical degrees of freedom within the illusionary three-dimensional environment. A significant detriment with other technologies is that students can quickly become disoriented because of the infinite freedom within the three-dimensional environment, that is, the ability to manipulate objects and viewer independently. By affixing either object or environment in the VR clip, learners can more readily interact and understand the presented materials. Limitless navigation during learning can often defeat the educational objectives (Mohler, 1997).

EDUCATIONAL MATERIALS FOR MATERIALS SCIENCE AND ENGINEERING EDUCATION

Often one of the difficulties in presenting science or engineering content is that the concepts being portrayed are microscopic in detail. From biological cell structures to the structures of atoms, learner understanding of the content is often limited by the media that is being used to present it. Frequently science and engineering texts provide abstract, two-dimensional drawings, which require interpretation by the reader. More often than not, spatial ability wanes and thus student understanding of such drawings, and the microscopic details they represent, is hindered.

As an example of an interactive multimedia program for engineering students and in an effort to enhance the understanding of materials science concepts, McGraw-Hill publishers worked with the Department of Computer Graphics at Purdue University to create an ancillary CD-ROM called *Materials in Focus* to accompany one of its materials science texts. The CD-ROM was designed to provide interactive multimedia components that would enable students to better understand the minute details and interactions of materials on which the discipline focuses. The CD was also designed so that instructors could use the assets in lecture and demonstration sessions to better engage students in active learning.

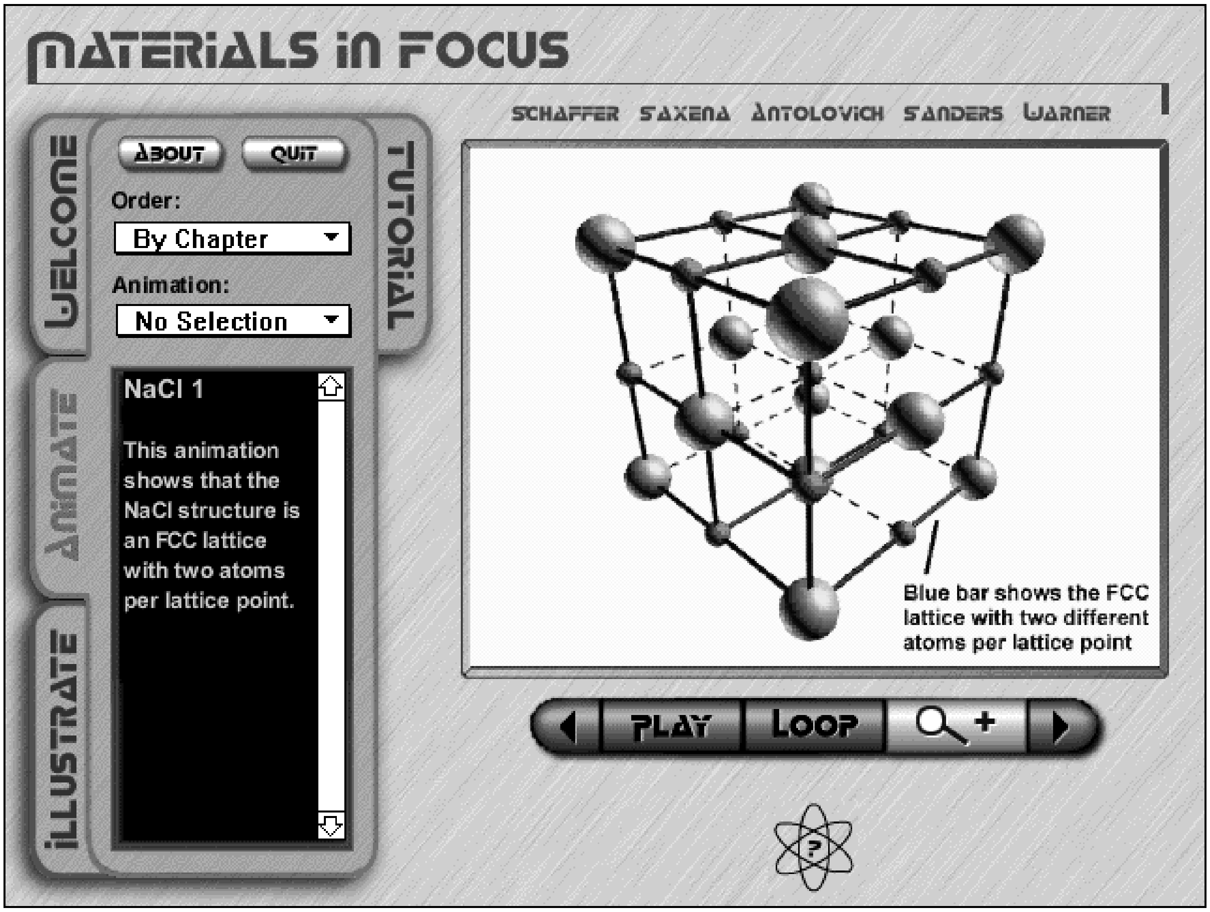
Using VR technology, the CD-ROM provides the ability to navigate a variety of structures and elements. Rather than presenting linear video clips or static images, the CD provides interactive components that the student directly manipulates. Using multimedia technology students can examine an NaCl molecule as shown in Figure 1a, explore a diamond crystal as shown in Figure 1b, study a zinc-blende crystal as shown in Figure 1c, as well as actively learn about a wealth of other concepts.



(a) (b) (c)

Figure 1. Using the CD students can (a) examine an NaCl molecule, (b) explore a diamond crystal structure, or (c) study a zinc-blende crystal.

In most instances the *Materials in Focus* was the first exposure that students had with VR technology as well as interactive multimedia directly related to materials science. Due to this, the interface for *Materials in Focus*, shown in Figure 2, was designed for simplicity as well as to mimic the Windows operating system controls. As issued elsewhere in this paper, an important design consideration for interactive multimedia tools is the design of the interface. In such tools, the content is what is important. Navigation should be easy, utilitarian, and unintrusive. The interface presents the typical tabbed style with drop-down menus for selections. All the buttons are appropriately labelled and sized and use a dual-coding approach for interaction.



Order: By Chapter

Animation: No Selection

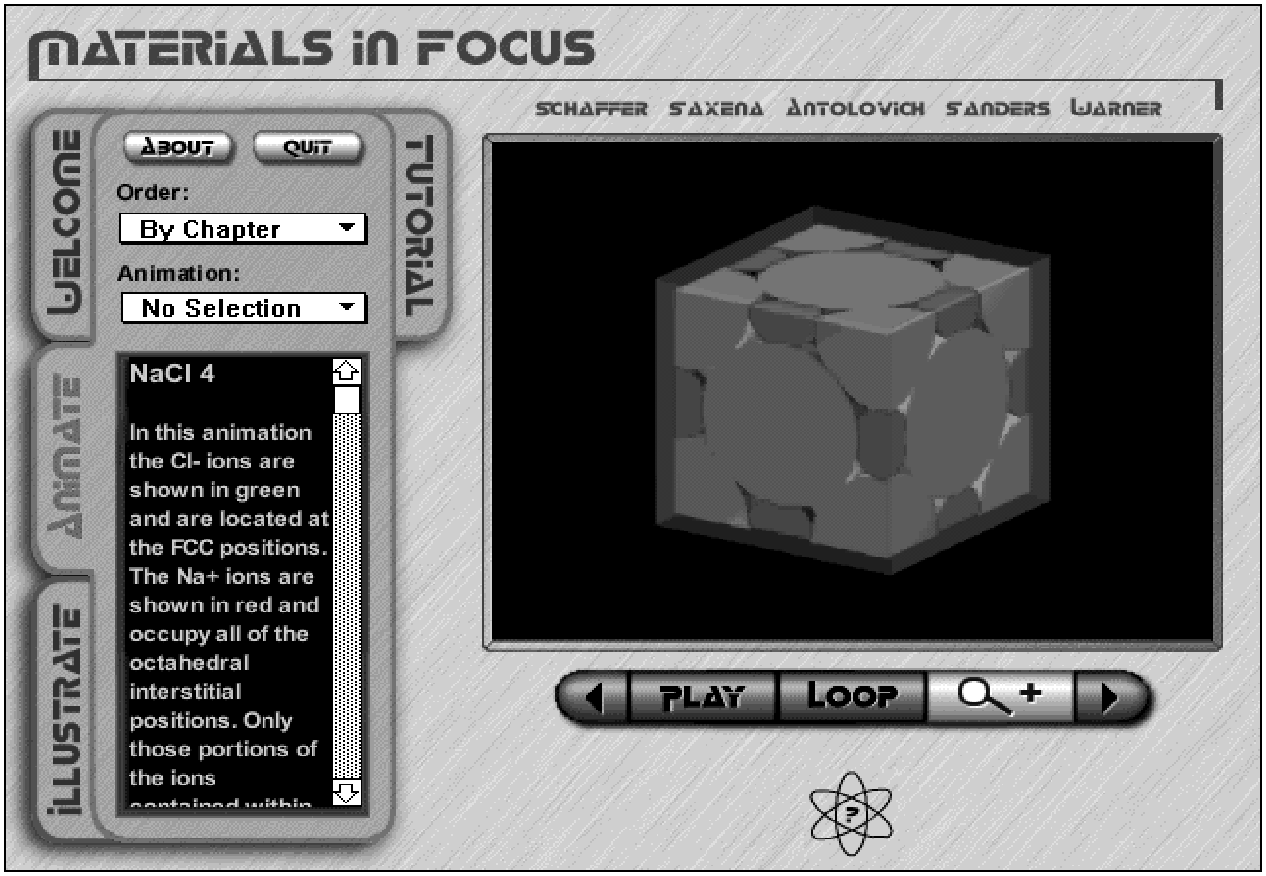
NaCl 1

This animation shows that the NaCl structure is an FCC lattice with two atoms per lattice point.

Blue bar shows the FCC lattice with two different atoms per lattice point

Figure 2. The interface for *Materials in Focus* was designed to be easy to use.

Although not statistically validated, comments received concerning the VR components in *Materials in Focus* indicated that students were better able to build a cognitive model of the content being presented. Students were not only able to visualize a structure, but also manipulate it and view it from a variety of locations. Relationships between particles, as well as an overall understanding of a composition, were more readily understood, as shown in Figure 3. Students could visually compare the arrangement of atoms and molecules, something that was mentally dependent when only static orthogonal views were used. An added benefit for the student was the ability to compare the two-dimensional drawings found in the text with the three-dimensional arrangement displayed in the CD's VR components. Thus students were able to visualize the 2D arrangement and then compare their mental image with the true 3D arrangement in the VR clip.



Order: By Chapter

Animation: No Selection

NaCl 4

In this animation the Cl- ions are shown in green and are located at the FCC positions. The Na+ ions are shown in red and occupy all of the octahedral interstitial positions. Only those portions of the ions

Figure 3. VR clips allowed students to dynamically interact with compound structures giving them a better understanding of relationships and structures.

CONCLUSIONS

Engineering educators must be continually looking for strategies to implement more effective instructional approaches. Technology is advancing rapidly and is beginning to provide educators with a wealth of potential tools. The future of education is in finding those technologies that enable active learning experiences for students. Yet, the utilization of the computer and other instructional technologies, including multimedia and animation tools, must be governed by the literature in learning, learning styles, and instruction. Similarly such tools must be statistically validated.

Interactive multimedia is quickly becoming a media of choice for learning and information distribution throughout the nation and the world. It is being heavily incorporated into our society in areas such as education, marketing, and training due to its apparent success as a medium for the transfer of information. Engineering educators should use interactive multimedia in the presentation of concepts where practical, applicable, and valid. New tools should be developed to better communicate engineering concepts to students using new and unique technologies. Concurrently, engineering educators must undertake research to determine the level to which interactive multimedia is effective in advancing engineering students understanding of engineering concepts as well as defining those technologies that most successfully impact student learning.

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