Design and Implementation of Interactive Online Tutorials for Introductory Soil Science Courses

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ABSTRACT

Introductory soils courses contain many physical and chemical concepts on a microscopic level that are often unfamiliar to students. Hence, many undergraduates in agriculture consider it to be one of the more difficult introductory courses. With the advancement in information technology, difficult concepts can now be modeled and delivered in an interactive format that allows students to develop a more solid understanding of basic soils. Accordingly, the objective of this project was to develop interactive tutorials for clay mineralogy and cation exchange capacity (CEC) that could be delivered over the World Wide Web. For the clay mineralogy tutorial, the students were introduced to the basic building blocks of clay minerals, the tetrahedron, and octahedron. From there, these were polymerized and combined into various layer silicate minerals. For each of the minerals a QuickTime virtual reality (VR) movie allowed the student to rotate the structure with a mouse. For the CEC tutorial we used a Crystalmaker model of a montmorillonite particle. Exchangeable cations scaled to their hydrated radii were placed in the interlayers of the montmorillonite particle to satisfy the charge developed via isomorphic substitution. Both the exchangeable cations and clay particles oscillated in the model to simulate Brownian motion. Cations in solution were programmed to move and exchange with cations on the surface of the clay particle, thereby demonstrating stoichiometry of the exchange reaction and the concept of CEC. These tutorials allow the student to move through a concept at their own pace and are ideally suited for distance education.

Topics that are hard to conceptualize are difficult to learn for many students. Interactive tutorials provide an inexpensive, promising approach to teach these concepts because they provide a dynamic visual experience that complements lectures and text. This is especially crucial in introductory courses because many of these concepts provide the foundation for subsequent understanding.

Soil science courses are important for students in environmental science, agronomy, forestry, and horticulture. Yet, the introductory soils course is often considered by many undergraduates to be one of their more difficult courses. Much of this difficulty appears to be due to the volume of information that is covered, as well as the abstract or conceptual nature of the material. An understanding of concepts from chemistry, biology, physics, and geology is necessary for mastery of soil science. Furthermore, many of the physical and chemical processes in soils occur on a microscopic level, which means these processes are often unique to soil science and are difficult for students to visualize.

Student understanding of some of the more difficult concepts from clay mineralogy, cation exchange, and sorption may be enhanced if displayed in a three-dimensional, rotational, interactive format. Previously, such tutorials could have been developed only with the help of a competent computer programmer. Now commercially available software packages are available that allow relatively unsophisticated users to create accurate interactive three-dimensional models that can be transmitted and displayed on the Web. This greatly assists students who have difficulty in converting two-dimensional images into three-dimensional phenomena. Due to their interactive nature, each student can move through the tutorial at his or her own pace.

The objective of this manuscript is twofold. The first is to explain how we used readily available software to construct interactive, online tutorials that provide dynamic visuals and supporting text to explain complex, conceptual knowledge. The second is simply to tell soil scientists about the availability of our interactive online tutorials on clay mineralogy and CEC. The first objective has value as a template for other instructors who are seeking to convert their traditional lectures into interactive online teaching. The second objective is to let the soil science education community know that these tutorials are available for their general use.

Clay mineralogy and CEC were chosen because these topics are considered to be some of the more difficult concepts in introductory soil science. Additionally, these processes occur on the microscopic level and are often difficult for students to visualize. These tutorials demonstrate the basic concepts of clay mineralogy and CEC and can be modified to emphasize specific clay minerals and exchanger compositions. Furthermore, concepts such as pH-dependent charge development and adsorption–desorption reactions of nutrients and contaminants can be developed. Although these tutorials were designed for introductory soils, they are well suited for other soils courses that discuss these topics. The tutorials described below can be accessed at the following URLs:

http://soils1.cses.vt.edu/MJE/CSES3124/CSES3124.html
http://soils1.cses.vt.edu/MJE/ENSC4734/ENSC4734.html

MODEL DEVELOPMENT

Clay Mineralogy Tutorial

A tutorial on clay mineralogy was developed to help students visualize and understand the structure of common phyllosilicate clays. Crystalmaker 4.0, an interactive crystallography program for Macintosh platforms, was used to create QuickTime virtual reality (VR) movies of phyllosilicate clays. The software has an extensive library of common soil phyllosilicate minerals as well as the ability to create minerals

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Abbreviations: CEC, cation exchange capacity; VR, virtual reality; EDL, electrical double layer.

using crystallographic data. QuickTime movies are excellent for teaching purposes, because they allow the student to rotate the three-dimensional model using the computer's mouse. Furthermore, the QuickTime plug-in can be downloaded free of charge for either PC or Macintosh platforms from Apple's QuickTime Web site.

The clay mineralogy tutorial allows the student to read through text and then click on a model representing a concept or a particular clay mineral. The student can then rotate the model on the screen using the mouse. The various atoms and molecules are color-coded, with a corresponding key in the text, to enable the student to easily distinguish between different elements and molecules (for example, aluminum is always a light blue, magnesium is always yellow).

The tutorial begins by discussing the basic building blocks of phyllosilicate clays, the tetrahedron, and the octahedron. Each is displayed in polyhedral, ball-and-stick, and space-filling representations (Fig. 1). By displaying all three views a student can view the various representations of clay mineral models that are often found in soil textbooks (Brady and Weil, 1999; Sparks, 1995). Furthermore, it allows the student to see differences in size between a cation and its coordinated anion as well as the individual polyhedra. This also introduces the student to the *hard-sphere* model of atom packing, which is often used to predict atomic arrangements in crystal structures (McBride, 1994). After the student views the individual octahedron and tetrahedron, these units are linked and displayed as tetrahedral and octahedral sheets. These sheets are then linked to form the 1:1 clay mineral kaolinite. As with the individual octahedron and tetrahedron, kaolinite is displayed in

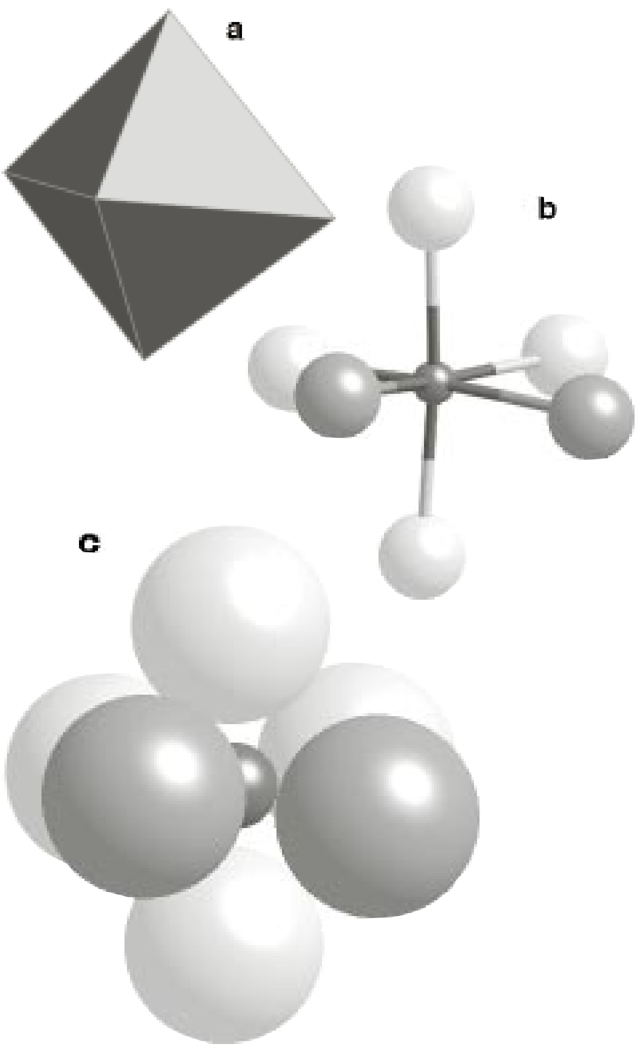

Fig. 1. Static image of Quicktime VR movies showing the octahedral building blocks for the phyllosilicate minerals created by Crystalmaker 4.0. (*a*) Polyhedra model, (*b*) ball and stick model, (*c*) space filling model.

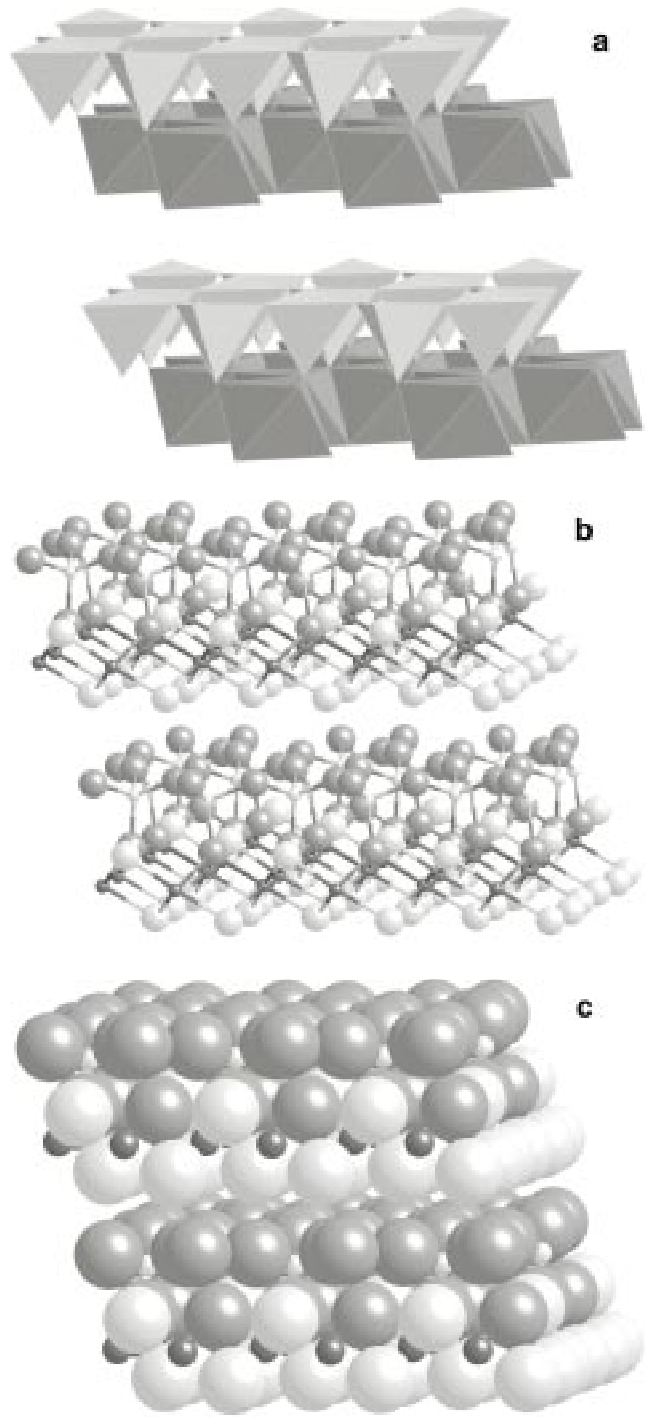

Fig. 2. Static image of Quicktime VR movies showing kaolinite created by Crystalmaker 4.0. (*a*) polyhedra model, (*b*) ball and stick model, (*c*) space filling model.

polyhedral, ball-and-stick, and space-filling representations (Fig. 2). This allows the student to see how the individual sheets are linked and allows him or her to understand how a 1:1 layer is held together. This will become important as a student learns about 2:1 clay minerals and their expanding and semi-expanding properties. After the basic concepts of aluminosilicate structures are understood, the concept of isomorphic substitution is introduced, which allows a student to develop selected 2:1 clay minerals as well as the 2:1:1 mineral chlorite. The student can see how isomorphic substitution affects layer charge, which, in turn, affects the degree of expansion of the various 2:1 clay minerals.

Cation Exchange Capacity Tutorial

A cation exchange capacity tutorial was developed to allow the student to visualize, in three dimensions, the concept of cation exchange on a clay particle. Both Crystalmaker 4.0 and Macromedia Director 7.0 were used for the demonstrations presented in this tutorial. Macromedia Director was used to create Shockwave movies that can be viewed on the World Wide Web using the Shockwave plug-in, which can be easily downloaded at no charge. As with the clay mineralogy tutorial, this tutorial allows the student to read through text and then click on a model that represents a concept. The tutorial begins with the discussion of isomorphic substitution, a concept that was developed in the clay mineralogy tutorial. However, we feel it is important that each tutorial be an independent, stand-alone module. Our tutorial uses the 2:1 clay mineral montmorillonite for all demonstrations. Isomorphic substitution begins when Mg^{2+} replaces an Al^{3+} in the octahedral layer, and is represented by changes in the color of the polyhedron. Similar to the clay mineralogy tutorial, the student can rotate these three-dimensional models to view different orientations. Using the quantity of isomorphic substitution in the octahedral layer (18 mol_c $mineral^{-1}$), and the molecular weight of the montmorillonite particle (8741.1 g $mineral^{-1}$), the student is shown how to calculate CEC for the clay mineral:

$$\frac{18\ \text{mol}_c}{\text{mineral}} \times \frac{\text{mineral}}{8741\ \text{g}} \times \frac{1000\ \text{g}}{\text{kg}} \times \frac{100\ \text{cmol}_c}{\text{mol}_c} = \frac{206\ \text{cmol}_c}{\text{kg}}$$

The total CEC is slightly higher than in most naturally occurring montmorillonite clays (but is in the range of CECs for pure 2:1 clay minerals) and was used solely for the purpose of the demonstrations.

After the concept of isomorphic substitution is developed and demonstrated, the student is introduced to the basics of the electrical double layer (EDL) theory, aided by the use of a Shockwave model. In this demonstration, the surface charge of the montmorillonite is satisfied by the adsorption of cations and the repulsion, or negative adsorption of anions (Fig. 3). The EDL and the bulk solution contain oscillating ions and

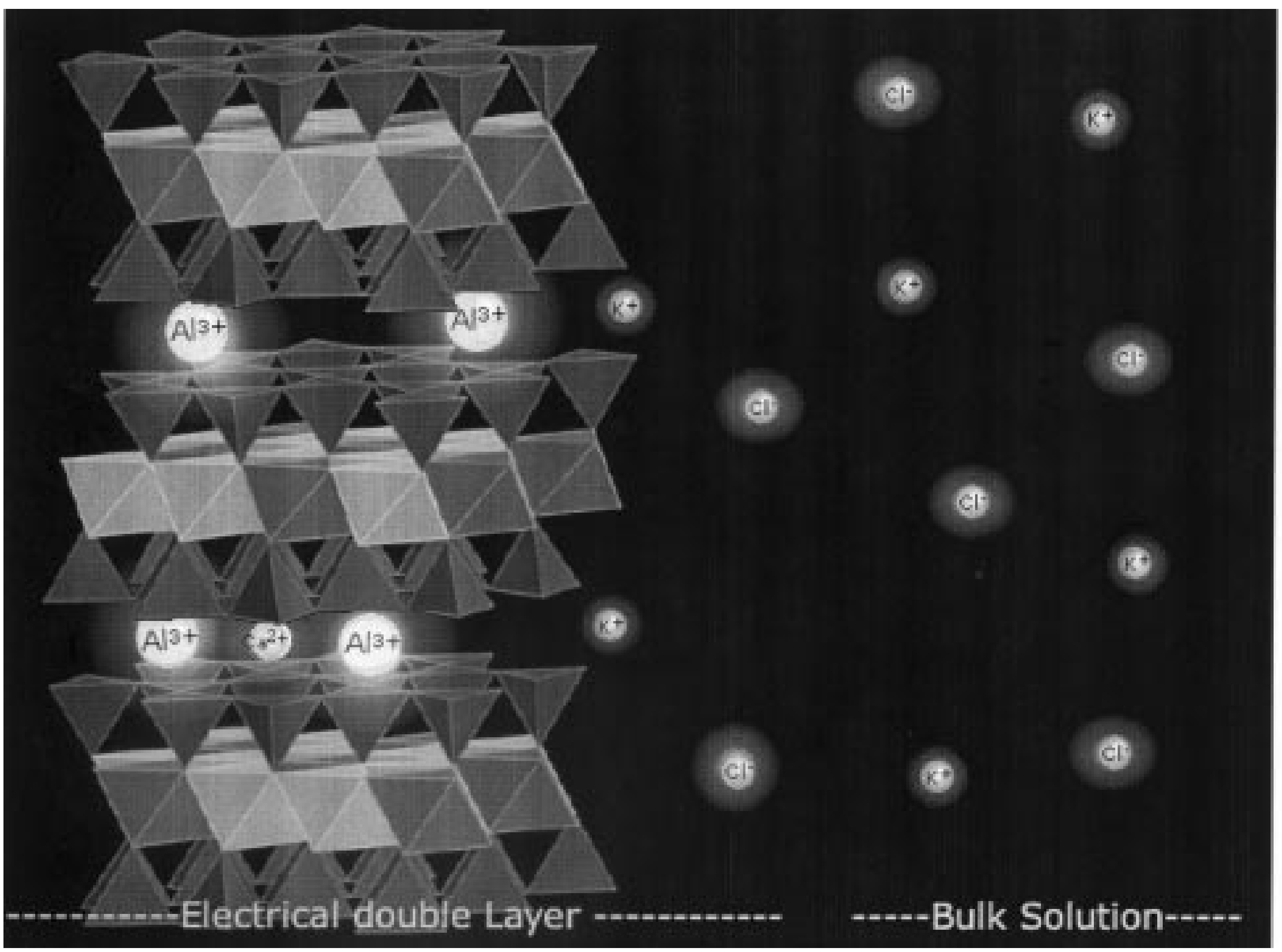

Fig. 3. Static image of a Shockwave movie demonstrating the basic concepts of electrical double layer theory.

Table 1. Hydrated radii used for the scale cation representations in the CEC tutorial.

Ion	Hydrated radii†
Al^{3+}	9.0
Ca^{2+}	4.5
K^+	3.0
Cl^-	3.0
H^+	--

† All hydrated radii from Lindsay (1979) except Ca^{2+} from Gast (1977).

clay particles to simulate Brownian motion, thereby creating a more realistic depiction of what occurs at the molecular level. Color-coded scaled representations of the hydrated radii are used in the EDL and CEC demonstrations. This allows the student to identify each cation and anion in solution or those adsorbed to the exchange complex. Hydrated radii for each cation (except Ca^{2+}) were obtained from Lindsay (1979) (Table 1), and the cations represented in the simulations were proportioned according to these values. The composition of the exchange complex (base saturation 20%) was modeled after a typical southwest Virginia valley Ultisol that had not been limed (USDA, 1980).

The final model demonstrates the concept of cation exchange on the surface of a montmorillonite particle and introduces basic concepts of cation exchange capacity. Such concepts include the stoichiometry of the exchange reaction, base saturation, and the selectivity of cations for the exchange complex. Three Shockwave movies are presented that demonstrate a monovalent cation for monovalent cation exchange, monovalent cation for divalent cation exchange, and divalent cation for trivalent cation exchange. Figure 4 illustrates several frames of the divalent cation for trivalent cation exchange Shockwave movie. The Shockwave movies show the movement and exchange of the cations in the aqueous environment for the cations adsorbed to the clay surface. In conjunction with the demonstration of the divalent–trivalent cation exchange, the concept of soil acidity and neutralization is developed in the text and is demonstrated by showing two Ca^{2+} cations exchanging for three Al^{3+} cations.

DISCUSSION

The two interactive online tutorials are ideally suited for teaching the basic concepts of clay mineralogy and cation exchange to students in introductory soils courses. These tutorials are intended for individual and distance-based learning environments. At any time during the tutorial the student can return to the text or redisplay a model. Furthermore, these tutorials can be modified for use in upper-level courses in soil fertility, soil chemistry, and pedology. Analogous tutorials could also be developed for many concepts discussed in soil physics. It is advantageous that these tutorials are Web-based, because anyone with access to the Internet can view them. The only added requirements are the appropriate plug-ins, which can be easily downloaded from a link provided with the tutorial at no cost.

The CEC tutorial can be easily modified to show different levels of base saturation and analytical methods for deter-

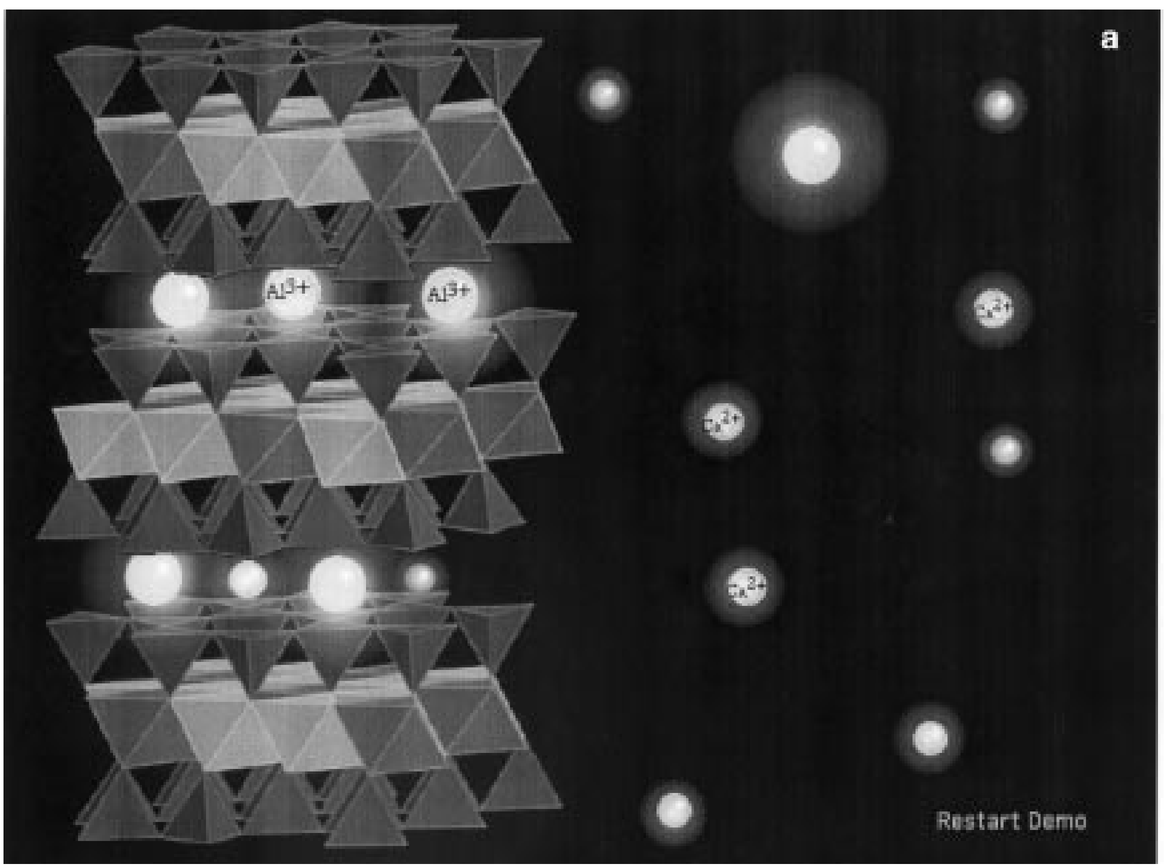

Fig. 4. Static image of a Shockwave movie demonstrating three Ca^{2+} cations exchanging with 2 Al^{3+} cations. (*a*) The beginning of the exchange reaction, (*b*) Ca^{2+} cations as they approach the Al^{2+} cations in the interlayer, (*c*) the Al^{3+} cations moving into the bulk solution.

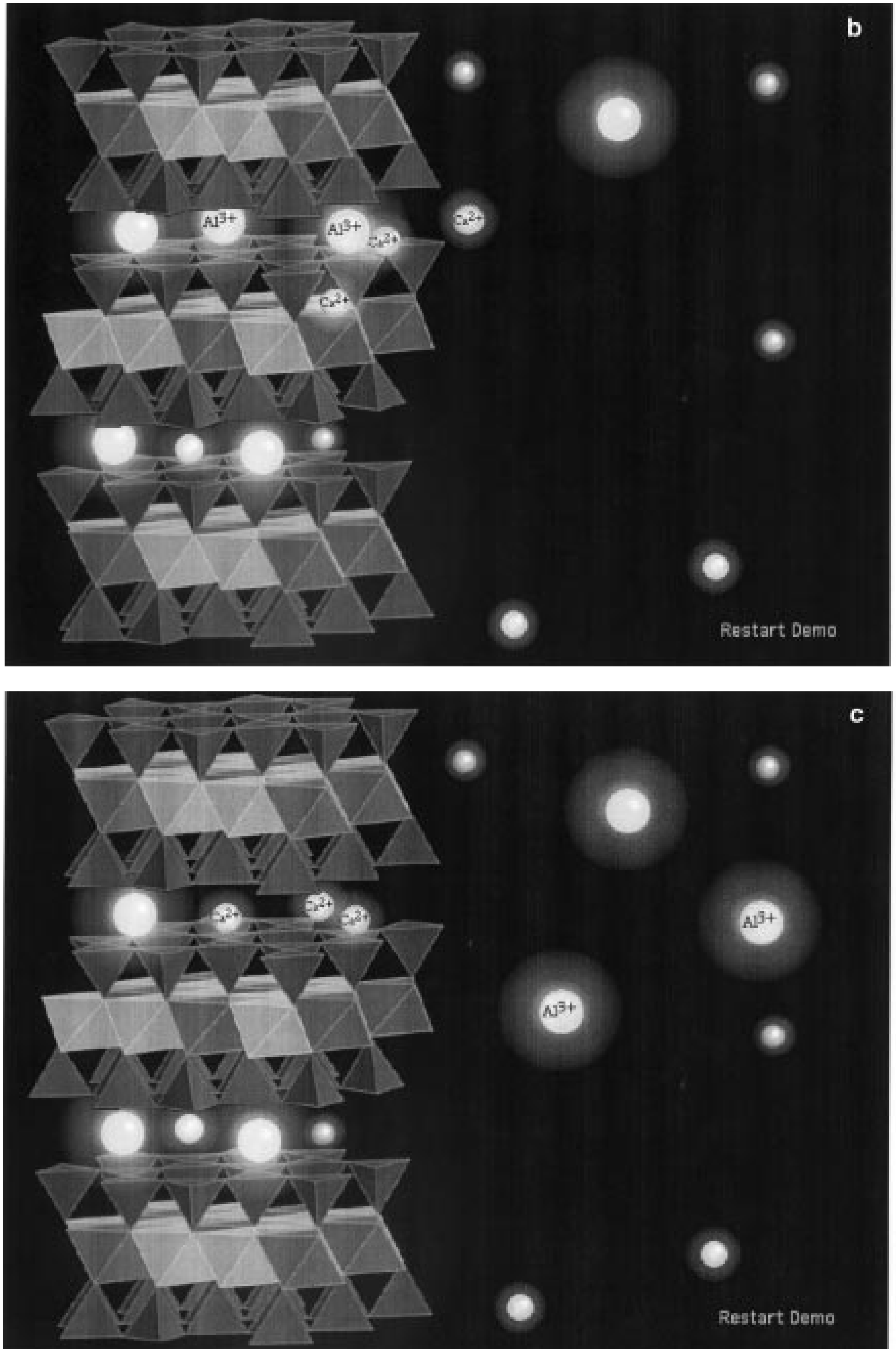

Fig. 4. Continued.

mining CEC (i.e., single and double wash method). The single wash method consists of the mass replacement of the existing exchanger phase composition with another cation, while the double wash method consists of the saturation of the exchanger phase with a cation and the subsequent mass replacement with another. These CEC tutorials can also be modified, or new ones could be developed, to demonstrate concepts such as pH-dependent charge, inner vs. outer-sphere adsorption, and redox reactions.

The models presented in each tutorial are representations of clay mineralogy and cation exchange reactions that occur in soil environments. Because these processes are submicroscopic and complex, actual reactions will be more complex than those demonstrated. However, for the purposes of teaching, these models do a thorough job of introducing some important and difficult concepts. The interactive nature of these tutorials allows a concept to be thoroughly mastered without a teaching assistant or an instructor present. Furthermore, since these models are Web-based they can be used by instructors throughout the world to teach similar concepts. We believe this has the distinct advantage over static models that demonstrate similar concepts (Guertal and Hattey, 1996). Results from an informal survey of students in introductory soils courses indicated that these tutorials enhanced their understanding of clay mineralogy and cation exchange capacity.

As mentioned previously, the above tutorials were developed with commercially available software. Both Crystalmaker 4.0 and Macromedia Director 7.0 director can be purchased with academic discounts for under $250.00. Crystalmaker 4.0 is an extremely user friendly program and the QuickTime VR clay mineral models can be easily developed. Macromedia Director 7.0 is a more difficult program to use and has a fairly steep learning curve. However, most universities have computer support staff that can help with using the program. In addition to the above programs one must also have a basic understanding of html to create the online tutorials. Both the clay mineralogy and CEC models were created in about 40 h. The Web pages and text took an additional 20 h to create. Both tutorials have also been modified (and continue to be modified) several times based on comments from students and colleagues. The flexibility and compatibility of the software allows one to create simple or complex models of many different processes that occur in soils. Furthermore, models can be developed to be used in the classroom without the use of the World Wide Web. This allows one to create more complex models that would be difficult to deliver via the internet due to size constraints.

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