Teaching Science in Virtual Reality with a Freehand 3D Illustration

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1 Introduction

We present the design of an immersive virtual reality (IVR) illustration and its use in teaching a biology lesson on the active structure of a termite mound. Educators at all levels use illustrations in textbooks and lectures to enhance students' comprehension of new information because they present material in an intuitive and interesting fashion [2]. Computer graphics has a rich history of application in conveying information to novice audiences, including the early use of IVR in architectural prototyping walkthroughs [1] and the interactive, 2D educational illustrations of the Exploratories project [8]. Our freehand termite mound model combines the advantages of IVR and nonphotorealistic rendering to effectively communicate a difficult scientific concept and improve upon the traditional mode of instruction through pictures.

The mound constructed by the savannah-dwelling African termite *M. bellicosus* is a fascinating example of artificial environmental regulation by animals. A clay construction two meters tall perforated with internal air channels, its three-dimensional structure provides thermoregulation and waste gas exchange for the nest at its base [6]. This structure and its interactions with the environment can be difficult to convey in text and 2D illustrations. We used CavePainting [4], a freehand modeling program that runs in the CAVE virtual reality environment [3], to design a simple, non-photorealistic cutaway model of the mound that includes convection currents and gas exchange. Since the model was intended to be used for instruction, its design and the design of the accompanying lecture proceeded in parallel. Once both were complete, a class of undergraduate biology students was brought into the CAVE in groups of six to eight for fifteen-minute lectures.

2 Presentation

As the students entered the virtual environment, they saw in front of them a life-size model of a termite mound, its peak just higher than their heads. Many viewers can be in the CAVE simultaneously, their views all controlled by a single user. The lecturer had this control and navigated to the opposite side of the mound; here a section had been cut away to reveal the nest at the base and the air channels

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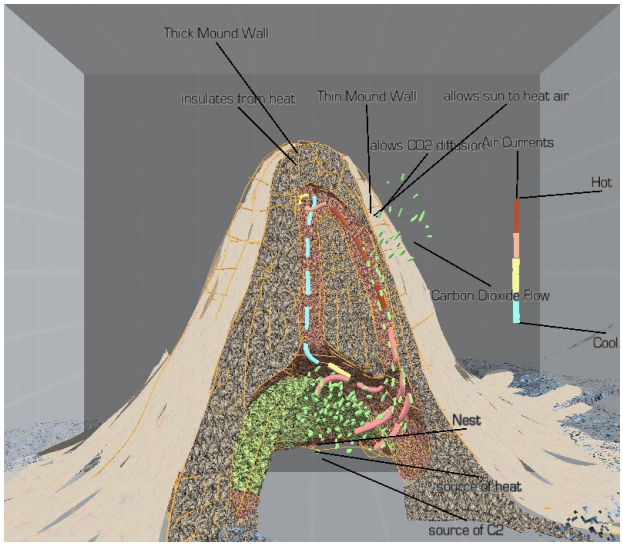

Figure 1: An external view of the mound revealing its structure, a solar-driven convection current, and diffusing carbon dioxide. Note the false coloring of the nest at the base and the reduced detail of the outside of the mound.

Figure 2: The lecturer and two students riding the convection current as it ascends the mound. Several viewers may be in the CAVE simultaneously, sharing one view, which allows a lecture to be delivered to many students at once with the accompanying illustration.

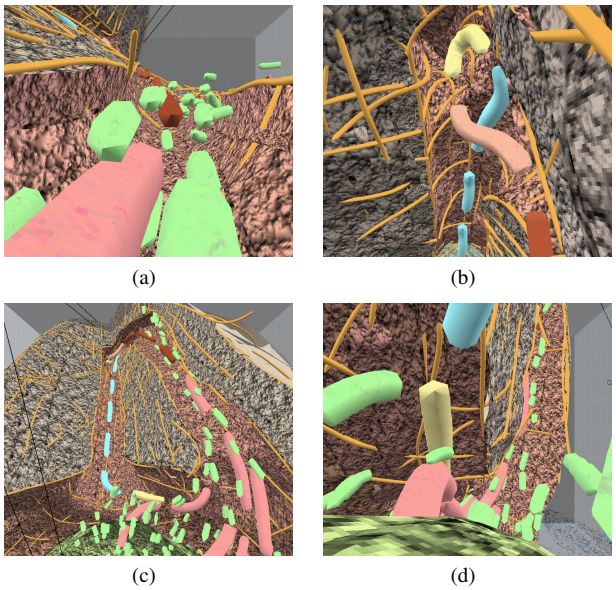

Figure 3: Virtual reality offers complete flexibility of viewing angle and scale to observe all features of a single model.

in the mound above. As the lecturer explained first the structure and then the function of the mound, he activated further portions of the illustration that show a cyclic convection current and the carbon dioxide exchange that it facilitates (figure 1).

To give the students a sense of the scale of this structure, the lecturer then expanded the model, shrinking all the users down to the size of termites. Now the students could see the mound from within and follow the path of the air like a roller coaster as it cycles (figure 2). The lecturer repeated the material from before, now with an intense visual experience accompanying it that caught the students' attention. We expect this exciting presentation improved comprehension and future recall beyond what would have been expected from a traditional lecture with 2D illustrations [2].

3 Evaluation

Using a freehand virtual reality illustration to augment a science lecture facilitates learning for three reasons. As mentioned above, illustrations in general assist the educator by reinforcing concepts in an intuitive, memorable, and appealing way. Additionally, IVR presents models of 3D phenomena in their natural space, making them easier to understand for novices. Furthermore, the nonphotorealistic rendering (NPR) community has argued that simplified visual depictions have many advantages over strictly realistic models when used for instructional illustrations. Such images emphasize important features while de-emphasizing others and also convey an intrinsic sense of generality [7]. CavePainting supports the creation of painterly and organic models in the virtual space where they will be presented to the audience, whereas CAD programs emphasize precise modeling and do not allow the illustrator to experience the model in its intended virtual space. CavePainting therefore gives illustrators the beneficial tools of NPR and lets him or her engage in a design process fueled by constant visual feedback [5].

In addition to the theoretical advantages of this style of illustration, we can also confirm that it enhanced the educational experience of the students, who were enthusiastic about the lecture and the subject matter. One student, a junior concentrating in Evolutionary Biology, told us that despite prior "trouble visualizing the link between the physical structure of the mound and its capacity to cool the air within it", she came to "appreciate the mound's formation and function in a way that would have required a much greater time investment without the lecture in the CAVE. It was an eye-opening experience!" Sharon Swartz, the professor for the class, told us that a "fifteen-minute CAVE demonstration probably gave students better understanding than they would have gained from an hour-long in-class lecture."

4 Conclusion and Future Work

Illustrations enhance learning in all contexts, but computer tools allowed us to create a single illustration that conveyed more information in a more intuitive and intriguing way in support of an educational goal. The immersive, interactive 3D experience of the CAVE allowed students to better understand the spatial structure of a termite mound, and the visually simple but exciting presentation allowed the illustrator/lecture designer to focus each student's attention on pertinent details and impress them thoroughly in his or her memory.

We noted that the process of creating the illustration itself enhances the designer's understanding of the material. Students are sometimes assigned to draw diagrams as part of their work, and using CavePainting to design an illustrative model could similarly prove to be a self-educational experience. In addition, the idea of using IVR illustrations as educational tools could be advanced by combining freehand and data-driven models; for example, a volumetric model of a skull could be augmented with annotations and freehand strokes to better convey a desired idea. Such an approach would allow for models to be based on pre-existing material, minimizing the effort needed to create them, while still reaping the benefits of an NPR-style illustration.

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