How-To-Do-It

A Simple and Concrete Model for the Introduction of Cell Theory in the Secondary School

Ron Royer
Ron Haaseth

Models often may be useful for introducing abstract principles. As Renner and Stafford (1972) emphasize, "The development of the ability to create, use and evaluate models to explain natural phenomena should be a major concern of the . . . school science program." Naturally, the better a model accords with structural or operational principles of what it is intended to simulate, the better it will serve as a teaching aid. The mode of such accordance is *analogy*, a very important tool for cultivating the transition from concrete to formal operations as defined by Piaget. Because it is concrete and therefore observable, the "artificial cell" described first by Moritz Traube in 1864 offers a useful analogy system for introducing cell theory, one that appears to be particularly ideal for introductory life science curriculum.

In his classic book, *The Origin of Life*, A.I. Oparin (1953) describes Traube's unique chemical system:

> Traube placed a small crystal of copper sulfate in an aqueous solution of potassium ferrocyanide. At the surface of contact a membrane of copper ferrocyanide is formed, which is insoluble in water. This membrane forms a semipermeable bag around the copper sulfate. As the crystal gradually goes into the solution the osmotic pressure within the little bag increases all the time and finally the very thin and inelastic membrane tears. The copper sulfate solution escapes through the crack and, as it comes into contact with the potassium ferrocyanide solution, new copper ferrocyanide is immediately formed which repairs the break, but now the bag has somewhat increased. As this repeats itself, the little bag continually grows, assuming a definite shape and size. Traube thought that his artificial cell imitated the growth of real living cells and that the study of this model would lead to an understanding of the physicochemical causes of growth. (p. 54)

Having several times replicated and presented the above procedure, we are of the opinion that, while it is not as precise an imitation of life as he apparently thought it to be, Traube's model nevertheless does provide a means for systematic exposition of a number of important fundamental cell functions. In an uncluttered and concrete way, it introduces such concepts as membrane formation, osmosis, differential permeability, nutrient uptake and growth. It thus offers significant advantages to the life science or biology teacher who seeks to introduce these elements of cell theory at a fundamental level. For these reasons, we undertook the task of systematizing procedures to prepare and present Traube's model for use in the classroom.

Preparing Reagents

Potassium ferrocyanide is found most commonly as the crystalline trihydrate ($K_4Fe(CN)_6 \cdot 3H_2O$), at a cost of approximately $10 per 100 grams. This compound is only mildly toxic compared to other cyanides, but care should nevertheless be taken in its handling, and it is recommended that reagents be prepared only by the teacher.[1] We prepared the saturated solution of potassium ferrocyanide (0.812M), and, through successive dilutions, determined that the Traube cell is most efficiently generated in solutions between 0.1M and 0.05M.

Our trials showed that a ferrocyanide concentration greater than 0.1M produces membrane too quickly for ideal observation by students, whereas concentrations less than 0.05M tend not to generate a visible membrane. We found the optimal concentration to be 0.08M.

We found the best quantity for a class of 30 students to be about 100ml of solution, when each student uses a three-inch watchglass for viewing. Table I. lists quantities needed for the preparation of 100ml batches at the preferred concentration. These 100ml working batches may be prepared at room temperature, even as late as a few minutes before the time of the class in which they will be used.

It is important that $CuSO_4$ be crystalline and not granular in form. We found the ideal crystal size to be approximately 3-5mm in diameter. When too small a crystal (or a grain) is used, the $CuSO_4$ is used up too quickly and the membrane does not continue to grow. When too large a crystal is used, much of the process of membrane formation is masked from view by the crystal itself, especially when viewing is done with an overhead projector.

Presenting the Model

We found that two means are appropriate for presenting the Traube cell in the classroom: 1) Teacher-presentation using either an overhead projector or a projection microscope; or 2) as a student laboratory activity employing binocular dissection microscopes (10-50× magnification) as the viewing apparatus. The major draw-

Ron Royer is an assistant professor and program coordinator of science education at Minot State College's Div. of Sciences, Minot, ND 58701. During 1984-85, he was assistant professor of education, coordinating field experiences, serving as science education consultant and researching science teaching methods at the Univ. of Minnesota, Ann Arbor. Royer previously taught at the Univ. of North Dakota and at one time was assistant director of the Long Lake Conservation Center in Palisade, Minnesota. He earned his B.S. in Entomology from Iowa State Univ., where he entered a formal doctoral program in entomology with an emphasis in insect physiology and toxicology. He completed his M.A. in Biology at Bemidji State Univ. and his Ph.D. in Science Education at the Univ. of North Dakota. **Ronald C. Haaseth** is a senior research associate in the College of Pharmacy at the Univ. of Michigan, Ann Arbor, MI 48109. He has taught at Bellevue Community College, the Univ. of Washington and the Univ. of Puget Sound as well. Haaseth earned his B.S. in Chemistry from the Univ. of Puget Sound and his Ph.D. in Organic Chemistry from the Univ. of Washington. He has much research experience, including his current work on solid-phase synthesis of Enkephalin analogs.

---

[1] The principal handling danger arises when solid ferrocyanide compounds are heated and HCN is generated as a gas.

Table I. Amounts of crystalline $K_4Fe(CN)_6 \cdot 3H_2O$ used to prepare 100 ml batches of working solution at listed concentrations.

Concentration	*Amount of solid*
.05M	2.11 gm
.06M	2.53 gm
.08M	3.38 gm
.10M	4.22 gm

back of the overhead projector presentation (besides the problem of crystal opacity) is that only two-dimensional black-and-white representation is possible. Whenever it is feasible, we recommend using a dissection microscope or a projection microscope for viewing the Traube model.

To initiate the process of cell growth, place 2-3ml of the potassium ferrocyanide solution in a three-inch watchglass or petri plate on the stage of the viewing apparatus and add a single crystal of $CuSO_4$. (Care must be taken that the crystal and resulting membrane are entirely immersed in the solution.) The membrane will begin to form almost immediately. One must take care not to jar the medium after growth has begun, for the developing membrane is rather fragile. If the ferrocyanide concentration is too great, the membrane may collapse prematurely upon jarring and no longer be visible as a membrane.

With ferrocyanide solutions of 0.05 to 0.1M, cell growth will be observable for approximately 10 minutes, and the concentration-dependent variable will be cell size. Thus, although the model may be set up and viewed at single stations with dissection microscopes, whole-class presentation using a projection apparatus (preferably a projection microscope) also is possible since the full period of growth and change can be observed continuously and discussed as it happens, within the normal attention span of most students.

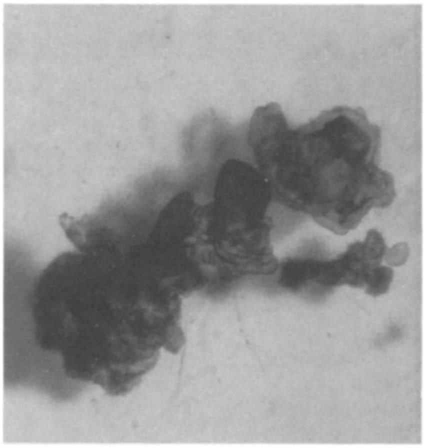
Suggestions for Further Investigation

For a determination of the objectives that this model may suggest in the building of a unit on cell theory, we found Hillman and Sartory (1980) worthwhile reading. The model serves well in our opinion to introduce the more difficult elements of introductory cell theory into any curriculum at any level. Of course, this must take into account the limitations imposed by the imperfect nature of models in general. The strength of the Traube model lies, we believe, in the fact that it presents such important concepts as cellularity and differential permeability without the burden of conflicting factors. Virtually every aspect of the Traube model can be drawn satisfactorily in one way or another into a useful analogy with living cell processes. We have alluded here to but a few of these possibilities.

Other sources we found interesting in the context of this model (particularly as they suggest possible subsequent steps in the development of curriculum around the model) include Klein's (1980) demonstration of diffusion and molecular motion, Kamrin's (1984) application of dyes to onion cells (this would transfer focus to the living material), and Journet's (1982) application of a similar model-based approach in getting at the problem of helping students to comprehend the role of randomness in evolution.

We also found worthwhile such approaches as that of Wilson (1980) in helping to define in the student's mind the conceptual distinction between living and nonliving matter. This distinction, one addressed originally by Traube himself in studying the ferrocyanide model, will of necessity be re-awakened in the mind of the inquiring student who participates in generating the "artificial cell."

Whereas the reaction producing the copper ferrocyanide membrane is chemical, the mechanism by which the membrane offers a diffusion barrier is physical. Thus, we subsequently discovered, the reaction can be performed with the solid and dissolved reagents interchanged; that is, using ferrocyanide as the crystal to generate a cell in a copper sulfate solution.[2] This fortuitous discovery led us to the notion that since the mechanism of growth in either system is principally mechanical-structural, it is conceivable that there are different, better and otherwise more practical reagents for accomplishing a similar model. We are presently searching for such reagents.



D_2: A single Traube cell (with $K_4Fe(CN)_6 \cdot 3H_2O$ "nucleus") at approximately two minutes of growth.

We are also working to understand more fully the dynamics of the Traube model on the molecular level. It is our belief that this search may yield not only further refinement of the analogy, but also a refined understanding of the principles of a relatively unique area in the domain of chemistry itself.

We hope to report further findings in appropriate journals as they become significant, and in the meanwhile we welcome reports from all who may test or employ the Traube model in their classrooms.

References

Hillman, H. & Sartory, P. (1980). A re-examination of the fine structure of the living cell and its implications for biological education. *School Science Review, 62*(219) 241-52.

Journet, A.R.P. (1982). Why Reproduce? A demonstration of evolution and the origin of life. *The American Biology Teacher, 44*(9), 543-7.

Kamrin, A.A. (1984). Demonstrating osmosis and anthocyanins using purple onion. *The American Biology Teacher, 46*(2), 116-7.

Klein, S. (1980). Diffusion and molecular motion: A visual demonstration. *The American Biology Teacher, 42*(8), 487.

Lewis, R.W. (1972). The structure of cell theory. *The American Biology Teacher, 34*(4), 209-11.

Oparin, A.I. (1957). (Anne Synge translation). *The origin of life on the earth.* New York: Academic Press.

Oparin, A.I. (1953). (Sergius Morgulis translation). *The origin of life.* New York: Dover Publications.

Renner, J.W. & Stafford, D.G. (1972). *Teaching science in the secondary school.* New York: Harper.

Stanek, J.A., Jr. (1983). Why don't cells grow larger? *The American Biology Teacher, 45*(7), 393-5.

Wilson, R.W. (1980). Living or nonliving: a game of twenty questions. *The American Biology Teacher, 42*(9), 566,569.

---

[2] We were alerted to this possibility entirely by chance through the apparently incorrect translation of Oparin by Synge (Oparin, 1957). She translated ferrocyanide as ferricyanide and reversed the reaction:

"Traube had immersed small crystals of potassium ferricyanide in an aqueous solution of copper sulphate and obtained globules surrounded by fine membranes of copper ferricyanide" (p. 88). Unlike potassium ferrocyanide, potassium ferricyanide produced no membrane in our attempts, regardless of its status as dissolved or crystalline reagent.