Educational research has demonstrated that the use of concrete objects or manipulatives in the classroom enhances problem-solving skills and conceptual learning. This project examines the use of manipulatives in a neurophysiology curriculum and assesses their effectiveness on student comprehension. Three activities, building an ion channel, building a nerve cell, and passive membrane properties, were developed using modeling clay and beads as manipulatives. Their effect on learning was assessed in a neurobiology class that had been divided into an experimental group that worked with manipulative-based activities and a control group that did not. After the experimental group had completed the manipulative activity, both groups were given a quiz. Students who had used manipulatives scored significantly better than those who had not. In a second study, students were given a quiz before and after completing a manipulative activity. Students who had used manipulatives showed the greatest grade improvement. These studies suggest that manipulative activities can be used to enhance learning in the neurophysiology curriculum.

Educators often use the lecture format in the undergraduate classroom with the expectation that students will learn concepts by reviewing their lecture notes and textbook. Evidence suggests that, when used exclusively, this method of teaching is an ineffective mode of instruction and an unproductive learning experience for many students. As a result, students may turn to rote memorization, a form of passive learning that has been shown to be inadequate for true comprehension and acquisition of problem-solving skills. Research has shown that, for effective learning to take place, students must actively participate in the learning process (8, 17). This suggests that the lecture format might become a more effective teaching tool if combined with activities that engage student learning.

Some experts feel that, for students to learn effectively, they must develop a conceptual framework in which to store and process newly acquired knowledge (19). One way that an instructor can engage students in this process is through the use of models and manipulatives. Manipulatives, small objects that can be handled by students in a way that enhances conceptual understanding, have been used extensively in the elementary and middle school science classrooms (3). Educators have demonstrated that, in these classrooms, manipulatives help develop and en-
hance problem-solving and critical-thinking skills (7, 20). Although precollege educators recognize the value of manipulatives as activities that promote understanding of abstract concepts, undergraduate faculty have overlooked them, assuming that students are able to grasp concepts without learning support. However, studies have shown that even student populations that are comfortable with abstract thinking will benefit by using manipulatives because it increases the efficiency of learning (7). Until recently, the major use of manipulatives in undergraduate science courses was in chemistry classes, where students learned to construct molecules with model kits. Pedagogical reform initiatives and advances in classroom technology have stimulated the development of alternative modeling activities that have been incorporated into science curricula (1, 2, 5, 6, 9, 12, 15, 16, 18).

Manipulative activities provide a number of advantages in the college classroom. For students struggling with the terminology of a textbook, they offer the opportunity to define a concept in their own terms and explore it in topic-relevant exercises. As students construct physical representations of concepts during manipulative activities, they resolve misconceptions associated with the language of the concept. Manipulative activities can also serve as effective vehicles for engaging students who come to the classroom with minimal understanding of the topic. Well-designed manipulative activity will build on a concept, taking it from the simplistic to the complex, thus incorporating all topic knowledge (4). Like other forms of active learning, manipulative activities address a spectrum of learning styles, appealing to the visual, auditory, and kinesthetic learners (20).

An effective manipulative activity can serve many functions in the learning process. To the instructor it serves as a form of assessment, providing a sense of student comprehension (14), whereas to the student it serves as a form of self-assessment, allowing them to challenge their understanding and evaluate it. A manipulative activity should also contain undefined components, forcing the student to “fill in the gaps” or improvise (14), thus providing the student with an opportunity for learning through discovery (14, 20). Ultimately, a manipulative activity should prompt students to construct a conceptual or qualitative model that will enable them to understand, store, and apply their newly acquired knowledge (10, 11, 13, 19).

One of the problems encountered in teaching physiology is that students often fall into the trap of memorizing facts without understanding the underlying concepts associated with them. Often, when discussing the molecular structure of ion channels, students seem to forgo understanding the functional significance of the molecular components in favor of rote memorization of the molecular structure. When asked questions about channels, students can readily describe channel structure but falter when asked to “build” a novel channel to specifications. Similar problems occur when passive membrane properties and functional organization of channels in neurons are taught. In an effort to remedy these situations, a series of learning exercises that used manipulatives to build conceptual models was developed.

This project examines the use of manipulatives in an undergraduate neurophysiology curriculum and assesses their effect on student comprehension. Three activities, “Building an Ion Channel,” “Building a Nerve Cell,” and “Passive Membrane Properties” were developed using readily available materials such as modeling clay and beads as manipulatives. The objective of this study was to determine whether manipulative activities improved conceptual understanding, dismantled misconceptions, and promoted critical thinking in the neurophysiology curriculum.

**METHODS**

Manipulative activities were tested in undergraduate neurobiology classes by using two protocols to evaluate activity effectiveness: 1) a population comparison protocol and 2) a value-added protocol.

In the population comparison protocol, an introductory lecture covering material relevant to activity objectives was presented to students. The class was then divided into two groups: an experimental group that worked with manipulative-based activities and a control group that did not use the manipulatives. After the experimental group had completed the manipulative activity, both groups were given a quiz that
assessed topic-related critical thinking (Fig. 1). The mean grade (±SE) was calculated for each group and significance determined using the Student’s t-test. Because all students in the class were expected to meet the same learning objectives, the control group also worked with manipulatives; however, this occurred after the learning study was completed.

In the value-added protocol, an introductory lecture covering material relevant to activity objectives was presented to students. The lecture was followed by a quiz that assessed topic-related critical thinking. The class was then divided into two groups: an experimental group that worked with manipulative-based activity and a control group that did not. When the experimental group had completed the activity, the entire class was given a second quiz (similar to the first), and the two grades were compared for each student (Fig. 1). The results are reported as improved, no change, or a worse grade. Significance was determined using one-way analysis of variance. Again, the control group also worked with manipulatives but after the learning study was complete.

On some occasions, the control and experimental groups were interchanged. Students who served in the control group for one manipulative activity might serve in the experimental group for another.

In addition, the instructor monitored student comprehension during the activity. The instructor performed visual evaluations throughout the activity and assessed student constructs for accuracy and completeness at the end of the activity. The instructor also assessed student comprehension orally at the end of the activity by asking questions related to the construct and its function. The oral evaluation provided the instructor with some understanding of individual participation in the activity. A spectrum of participation, ranging from the knowledgeable team leader to the uninformed passive participant, was observed; however, no effort was made to document or grade these observations.

RESULTS

Activity 1: Building an Ion Channel. The objective of this activity is to promote understanding of the structure of the ion channel and the functional signif-
icance of its component parts. Students are asked to construct protein components and then assemble them into a channel. During the exercise, the students explore the role of polar and nonpolar amino acids in channel alignment, specificity, and gating. As they progress through the exercise, students must think about the orientation of channel components and their functional significance.

In steps 1–3 (Fig. 2), students use clay to create the α-helical transmembrane protein structures that are seminal to channel structure. This section of the activity provides students with a sense of the orientation and organization of transmembrane sequences of channels. When students assembled the helical sequences to construct the channel, many remarked that they finally understood how the sequences could be organized to form a hole or channel. In steps 4–8, students are asked to label toothpicks as polar and nonpolar amino acids and place them appropriately. In this way, they are able to observe the orientation of channel proteins and amino acids within the membrane and explain the functional importance of amino acid placement. At this point, many students recognized that they did not understand the definition and functional significance of polar and nonpolar amino acids. Usually, this was resolved by group discussion. In some cases, students did not orient polar or nonpolar amino acids appropriately and were corrected by the instructor through a question-discussion session. In step 9, students design ion selectivity mechanisms by placing marshmallows around the mouth of the channel to represent amino acids participating in ion selectivity. This gives them the opportunity to discuss the role of amino acid placement with respect to the sphere of hydration. This part of the activity frequently caused students to admit that they did not understand the phrase “sphere of hydration” or how it affected channel selectivity and conduction. In step 10, students craft a hinged-lid protein from clay and attach it to their channel, providing them with a visual and conceptual model of a gating mechanism. The last step in the exercise, step 11, asks the students to view their model (Fig. 3) and summarize their understanding of its structure and function.

Students who participated in the manipulative activity demonstrated better comprehension of channel structure on quizzes. In the population comparison protocol, where the class was assessed after the activity, those students who had participated in the activity scored significantly better than those who had not [80.8 ± 2.5% (n = 10), 45.0 ± 3.8% (n = 12), P < 0.01; Fig. 4A]. In the value-added protocol, students were assessed twice, first after the topic-related lecture and second after the experimental group had completed the activity. A comparison of the two quiz grades showed that eight students who had participated in the activity improved their test scores, and two students showed no change in score. A compar-

### BUILDING AN ION CHANNEL

**Materials:** (for each team of 2-3 students)
- Children’s modeling clay
- 25 toothpicks
- 20 red stickers
- 20 yellow stickers
- 4 marshmallows

Work in teams of 2-3 to build an ion channel using modeling clay and toothpicks. As you work on the exercise, think about the characteristics common to all ion channels.

1. Take 4 equal size lumps of modeling clay and roll them into a snake about as thick as a pencil and 10 inches long. These are peptide chains that will be used to make a channel.
2. Transmembrane sequences of channels have an α helix structure. Coil each peptide chain into an α helix.
3. Roll 2 lumps of modeling clay into 5 x 6 inch sheets about 1/4 inch thick. These will serve as the lipid bilayer of the nerve cell membrane. Mark a 3 inch circle in each and remove the circle.
4. Place the transmembrane sequences around the circle of one membrane and connect them. You may need to add ropes of clay to do this. The α helices/transmembrane sequences should form a circle with a channel in the middle. Place the other clay membrane on top. Where do the ions pass? Where is the inside of the cell? Where is the outside of the cell?
5. Mark the end of 12 toothpicks with red stickers. These are the polar amino acid subgroups.
6. Attach 3 polar amino acid subgroups to each transmembrane sequence. Where do they go? Why are they located here?
7. Mark the end of 12 toothpicks with yellow stickers. These are the non-polar amino acid subgroups.
8. Attach 3 non-polar amino acid subgroups to each transmembrane sequence. Where do they go? Why are they located here?
9. Put marshmallows at the end of 4 toothpicks to represent the amino acids that form the selectivity filter. Place them in the appropriate area of the channel. Why are they located here? Should they be charged? Why? How would you change the placement of these amino acids for a large ion such as calcium? Why? How would you change the placement of these amino acids for a small ion such as sodium? Why?
10. Take another piece of modeling clay and roll it flat like a can lid. Use this as a model of the hinged-lid gate for your channel. Where should this be attached? Why?
11. Using a bead as an ion, follow the flow of the ion through the channel. Describe the function of the helical peptide, polar and non-polar amino acids, selectivity filter, and hinged lid.

**FIG. 2.** Building an Ion Channel.
ison of grades in the group that had not participated in the activity showed that four students improved their grades without the activity, and six showed no change in grade (Fig. 4B).

At the end of the activity, the instructor asked students to discuss their constructs. Students’ were assessed on their understanding of the location and function of the α-helices, polar and nonpolar amino acids, and selectivity filter. Most teams understood the orientation of the helices, although some did not realize that they could be connected and, hence, part of a single protein. About 10% of the teams had difficulty orienting polar or nonpolar amino acids and required instructor intervention to promote understanding. Most teams could build a selectivity filter but could not explain how it changed for larger ions such as calcium. This was clarified with team discussion and instructor intervention.

**Activity 2: Building a Nerve Cell.** The objective of this activity is to promote understanding of the location and functional significance of the spectrum of ion channels found in the neuron. Students are asked to use modeling clay to create neurons and synapses with craft bead ion channels. As students progress through the exercise, they expand their conceptual model of the neuron so that it can accommodate open/closed channel states and the functional significance of each channel during depolarization and hyperpolarization. In steps 1 and 2 (Fig. 5), students build a neuron with passive and voltage-gated channels, thus reinforcing their understanding of channel function. Often, as students place channels in the neuron model, they question the cellular location of the channels. Typically, they resolve the issue through discussion. In steps 3 and 4, students create axoaxonic, axodendritic, and axosomatic synapses at the neuron and insert neurotransmitter-gated channels appropriately. In this part of the exercise, students again review and reinforce their knowledge of synaptic structure while their understanding of the location and function of neurotransmitter-gated channels is challenged. In step 4, C and D, students use their model to explain how an axoaxonic synapse can alter action potential conduction. This often sparks discussions that clarify the events of the action potential. Finally, in steps 5 and 6, students use their model to review the events leading to threshold and the action potential. This discussion synthesizes the concepts in step 4 and challenges the students to apply their knowledge of the function of the ion channels and its role in generating a change in membrane potential. At this time, students may also find a gap in their understanding of how voltage-gated and neurotransmitter-gated channels generate a change in membrane potential, excitatory postsynaptic potential, or action potential. By working with their clay model
Students who participated in the manipulative activity demonstrated better comprehension of neuron structure and channel location on quizzes. In the population comparison protocol, where the class was assessed after the activity, those students who had participated in the activity scored significantly better on quizzes than those who did not [87.5 ± 3.8% (n = 10), 50 ± 8.0% (n = 12), P < 0.01; Fig. 7A]. In the value-added protocol, where students were assessed twice, all students who had participated in the activity improved their test scores (n = 10). A comparison of grades in the group that had not participated in the activity.
activity showed that six students improved their grades, three showed no change, and three scored worse on the second quiz (Fig. 7B).

At the end of the activity, the instructor asked students to discuss their constructs. Student responses were assessed on their understanding of 1) the location of channels, 2) the functional significance of channels in each location, and 3) the factors that regulated channel gating. Two common misconceptions became apparent at this time. The first dealt with the location of the neurotransmitter-gated channel. Frequently, students placed neurotransmitter-gated channels in presynaptic axon terminals only to discover their error when their model could not explain the events of postsynaptic depolarization and neurotransmitter release. The second misconception uncovered at this time related to channel gating. The majority of students had entered the class with the preconceived idea that channels are always gated, an idea not easily dispelled in lecture. As they reviewed the events of the action potential, they faltered as they explained the state of passive channels in their clay model. Team discussion, with occasional instructor guidance, usually resolved the issue.

Activity 3: Passive Membrane Properties. In this activity, students explore passive membrane properties, capacitance, and membrane resistance and reflect on their influence on nerve cell function and excitability. They learn that by manipulating these variables they can alter nerve cell properties lambda (λ) and tau (τ) as well as excitability. In steps 1 and 2 (Fig. 8), students are given membrane permeability values and asked to construct a soma with channels using clay and craft beads. This exercise is designed to provide students with an understanding of membrane permeability and its link to channel distribution and membrane potential. In steps 3–5, students define τ and its variables, capacitance and resistance, and then build clay and bead models that reflect variations of these parameters. Frequently, students begin the activity feeling that they have a working understanding of the formula for τ, however, when asked to build a nerve cell that modifies the variables capacitance and resistance, they waver. Again, by working with their model (Fig. 9) and talking to other group members, they clarify their understanding of the τ variables and are able ultimately to predict the shape of a postsynaptic potential. The activities in steps 6–10 are similar to steps 3–5 except that students explore λ by building a clay model of the neuron and modifying the variables membrane and cytoplasmic resistance. They are then asked to predict action potential velocity as they vary these parameters. The answers are not always readily apparent, and students usually problem solve as a group to provide them. Students are also asked to apply their understanding of λ to and explain the value of myelin. Usually they refer to their constructs for this explanation. By the end of the activity,
students are comfortable with their understanding and application of membrane resistance, capacitance, and cytoplasmic resistance.

Students who had participated in the manipulative activity demonstrated better comprehension of passive membrane properties on quizzes. In the population comparison protocol, where the class was assessed after the activity, those students who had participated in the activity scored significantly better than those who did not, $81.3 \pm 8.2\% (n = 10)$, $51.3 \pm 8.5\% (n = 12), P < 0.05$ [Fig. 10A]. In the value-added protocol, where students were assessed twice, seven students who had participated in the activity improved their test scores, and one student performed worse. A comparison of grades in the group that had not participated in the activity showed that three students improved their grades without the activity, four showed no change in grade, and one did worse. (Fig. 10B).

Figure 7.
Assessment of the Building a Nerve Cell activity. A: population comparison protocol; mean quiz scores ± SE of students who had used manipulatives vs. students who had not. B: value-added protocol; a comparison of pre- vs. postactivity quiz scores between students who had used manipulatives and students who had not. "P < 0.01.

Figure 8.
Passive Membrane Properties.

Materials: children's modeling clay
50-75 colored beads

Work in teams of 2-3. As you do this exercise, think about membrane permeability, membrane resistance, capacitance and cytoplasmic resistance.

1. Use modeling clay to make 2 equal size neurons. Place colored beads in the cell so that they reflect the permeabilities below.
   Na⁺ channel = red  K⁺ channel = blue  Cl⁻ channel = yellow
   Na⁺/K⁺/Cl⁻ ratio = 20/1/1  Na⁺/K⁺ratio = 1/20/2

2. Which cell is closest to resting membrane potential?

3. What is the definitions of a? Write the equation for a below.
   a. What are the 2 variables for a? A. ____________________
      B. ____________________

4. Make 2 somas using modeling clay and/or beads and vary A. How will a be different in each soma? Will this affect the IPSP?

5. Make 2 somas using modeling clay and/or beads and vary B. How will a be different in each soma? Will this affect the IPSP?

6. What is the definition of b? Write the equation for b below.

7. What are the 2 variables for b? A. ____________________
      B. ____________________

8. Make 2 axons using modeling clay and/or beads and vary A. How will b differ in these axons? Which axon is the action potential faster?

9. Make 2 axons using modeling clay and/or beads and vary B. How will b differ in these axons? In which axon is the action potential faster?

10. How does myelin influence b? Did you include it in your model? If not do so now.
At the end of the activity, the instructor asked students to discuss their constructs. Student responses were assessed on their understanding of 1) the structural variables of the neuron that influence $\lambda$ and $\tau$ and 2) how variations in neuron structure can influence the postsynaptic potential or action potential. By the time students had completed the activity, most had grasped the learning objectives. Occasionally, teams would not perceive myelin as a means of enhancing $\lambda$ until they had answered the last question of the activity.

**Assessment.** A survey was presented to students at the end of the course. In this assessment, students were asked to evaluate how manipulative activities, instructor lectures, class time group activities, and class time review of homework had helped them learn. Responses were graded as strongly agree (SA), agree (A), neutral (N), disagree (D), and strongly disagree (SD). Although modeling activities were favored, students seemed to prefer working in groups and class time review of homework. Modeling activities scored a response ratio of SA:A:N:D:SD = 50:44:6:0:0%. Class time group activities scored a response ratio of SA:A:N:D:SD = 61:33:0:0:6%. Class time review of homework scored a response ratio of SA:A:N:D:SD = 61:33:0:0:6%. Instructor lectures were the students' last choice of learning aids (SA:A:N:D:SD = 50:33:6:0:0%).

**DISCUSSION**

This project examines the use of manipulatives in a neurophysiology curriculum and tests the hypothesis that manipulatives can be used to improve conceptual understanding, dismantle misconceptions, and improve critical thinking. Two protocols, the population comparison protocol and the value-added protocol, were used to assess their effectiveness. Results from the population comparison protocol showed that manipulative activities can be used to enhance learning in the neurophysiology curriculum. Students who had participated in the activities scored higher on quizzes, indicating a better conceptual understanding of the topic than their peers. Although the results of the value-added protocol were not statistically significant, they showed a trend that suggests that manipulative activities can be valuable learning tools, since more than 70% of students who used manipulatives consistently improved their scores on a second
Activities appeared to develop and use conceptual models as they created the clay constructs of the activity. The activities also appeared to encourage students to challenge their understanding of the topic. As they built their clay models, students were frequently observed testing them for accuracy and effectiveness, and in the process testing their conceptual models. Additionally, manipulative activities promoted team learning. Students were directed to work in teams during the exercise and seemed to benefit from the group interaction and resources. Those observed working in groups appeared to learn more effectively and problem solve more successfully than those who chose to work independently. Group interaction also served as a means of identifying misconceptions or misinformation. When group discussion would reveal a discrepancy in the topic knowledge of the group, they would identify the misinformation and correct it.

Instructor observations indicated that the quality or sophistication of the clay constructs did not seem to affect student comprehension. Constructs ranged from the simple to the elaborate, and there appeared to be no consistent correlation between the complexity of the clay model and the depth of student understanding. What seemed to be critical, however, was the accuracy of the model. When the instructor observed an inaccuracy in a model, casual questioning indicated that student comprehension was inaccurate or incapable of explaining the exercise. Instructor intervention, usually in the form of questions, initiated a discussion and revision.

Although these studies demonstrate that manipulatives are effective in improving learning in a neurophysiology curriculum, it is clear that the manipulatives were not used in isolation but rather in combination with other pedagogies. Classroom observations indicated that peer interaction and student-instructor interaction were also important to the success of learning with manipulatives, and in their absence manipulatives might have been less effective. End-of-course assessments that polled students about the value of the various teaching activities used in the course indicated that students also felt that a combination of pedagogies was effective. The majority of
the students felt that class review and group activities, as well as manipulative activities, helped them learn.

Developing an experimental protocol to be used in an undergraduate course presented a number of challenges. For example, despite a clearly defined prerequisite, not all students came into the classroom with the same or sufficient knowledge base. In an effort to address this issue, a pre- and postassessment test, the core of the value-added protocol, was instituted to assess the actual learning that occurred and eliminate the variable of preexisting knowledge. To address the variety of learning styles found in the population, the protocol varied the students serving as controls. Students who served in the control group for one protocol might serve in the experimental group for another. In this way, varied learned styles were distributed among the control and experimental groups.

One of the problems encountered in the experimental design of this study dealt with topic exposure time in the control group. Because students in the control group did not participate in a manipulative activity during the experiment, they had less learning time or topic exposure time than the experimental students. Ideally, the control group would have been presented with an alternate learning activity as a replacement for working with manipulatives. Although such an activity might or might not have improved learning, it would have addressed the variable of additional study time. Unfortunately, this experimental design presented some difficulties. In a small undergraduate classroom where students are acquainted with one another, any discrepancy in the curriculum between one group of students and another is quickly noted and questioned. Also, because control and experimental students were in the same course, they expected to meet the same learning objectives, follow the same curriculum, and receive the same assignments for the purposes of grading. Because of this, students in the control group were not presented with alternative (and perhaps less effective) learning activities to replace the manipulatives; instead, they also used the manipulatives but only after the experimental assessment was completed. Future studies need to address this issue, perhaps by including an additional activity in the curriculum (a problem set, review sheet, etc.) that would provide the control group of students with similar exposure time to the topic.

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