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## Essay

# Garage Demos: Using Physical Models to Illustrate Dynamic Aspects of Microscopic Biological Processes

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Colorful PowerPoint presentations with detailed drawings, micrographs, and short animations have become the standard format for illustrating the fundamental features of cell biology in large introductory classes. In this essay, we describe a low-tech tool that can be included in a standard lecture to help students visualize, understand, and remember the dynamic aspects of microscopic cell biological processes. This approach involves use of common objects, including pipe insulation and a garden hose, to illustrate basic processes such as protein folding and cloning, hence the appellation “garage demos.” The demonstrations are short, minimizing displacement of course content, easy to make, and provide an avenue for increasing student–faculty interaction in a large lecture hall. Student feedback over the past 4 years has been overwhelmingly positive. In an anonymous postclass survey in 2007, 90% of the respondents rated garage demos as having been very or somewhat helpful for understanding course concepts. Direct measurements of learning gains on specific concepts illustrated by garage demos are the focus of an ongoing study.

## INTRODUCTION

Like many faculty, we began teaching cell biology by emulating those who taught us. Armed first with chalk and overheads, followed by PowerPoint slides, we lectured to several hundred students in large theaters about biological processes that are complex, dynamic, and often microscopic. As faculty, we believed the students understood the material and concepts covered in class because very few would ask questions. This perception was reinforced by murmurs of ascent when asked, “Did everyone understand that last point” and by shaking of heads when asked “Before I move on, does anyone have questions?” Students also believed that they understood the material because they could follow the logic in lecture and were capable of memorizing facts from the textbook. However year after year, we, and the students, were surprised and unhappy to discover through performance on exams that many had only a superficial understanding of the core concepts. To address this problem, we made additional slides in subsequent years to help clarify the concepts most consistently missed on the exams. Over several years, the number of slides per lecture grew to

the point that it was impossible to cover them all in a 50-min period, even when speaking at breakneck speed. Yet, there was no improvement in the depth of understanding based on exam performance. It seemed, paradoxically, that the additional information might actually reduce student understanding of basic concepts.

Recent technological innovations have made it easier for faculty teaching large classes to transition from purely didactic lectures to more diverse teaching styles (Knight and Wood, 2005; Caldwell, 2007). Through use of an audience response system (iClicker; Macmillan New York, NY) beginning in 2005, we discovered that most students were able to recall basic facts discussed in class. However, the static images used in lecture did not seem to be effective in conveying the dynamic aspects of biological processes, a component essential for understanding the concepts. Because previous studies had shown that animations can help students visualize dynamic processes (Stith, 2004), we began augmenting some of our in-class descriptions of biological processes with short computer animations. Although students reported that the animations were helpful, they continued to have trouble recalling the dynamic aspects of many basic cellular processes.

Based on experience of students in introductory physics, where large-scale in-class demonstrations had been very

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effective in solidifying understanding and ability to recall basic principles (Crouch *et al.*, 2004), we began experimenting with in-class demonstrations. We used large physical objects to represent microscopic biological structures and used these to illustrate dynamic processes. Early demonstrations in fall 2005, fondly called “garage demos,” made use of common items found in our garages, including polyvinyl chloride (PVC) pipe, rope, tarps, and rolls of toilet paper. Some required a glue gun and drill for assembly (such as phospholipids built from PVC pipes, a wire hanger, and Styrofoam balls), but we confess that some were cobbled together right before class (such as dirty socks pulled from neglected soccer bags to represent sister chromatids). The student response to in-class demonstrations was overwhelmingly positive. Feedback through iClickers and anonymous course evaluations also indicated that students felt the demonstrations were more useful than any other tools we used, including animations and clicker questions, for understanding the course material.

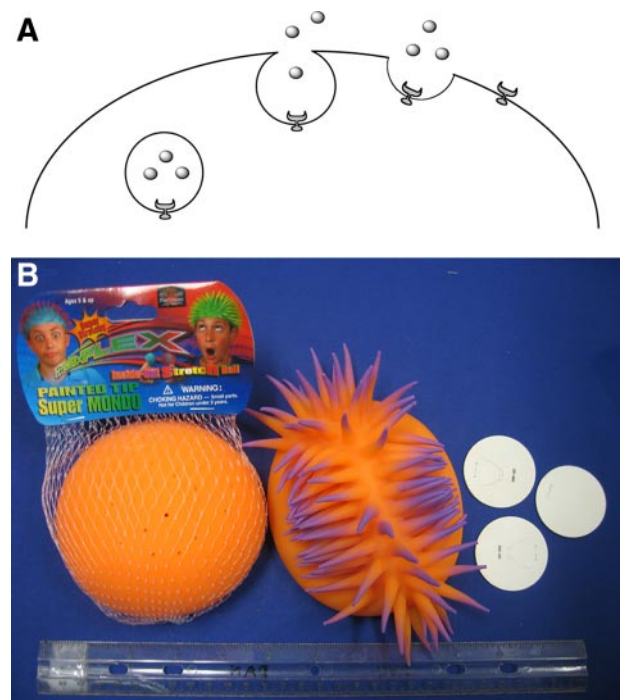
Guided by student feedback, we refined existing demonstrations, retired demonstrations that were too complicated, and developed new demonstrations. By fall 2007, almost all lectures included a demonstration. They were typically set up to reinforce understanding of processes or concepts initially presented using static PowerPoint images, similar to learning cycles used in physics (Crouch *et al.*, 2004; Beatty *et al.*, 2006). Inclusion of the demonstrations required ~5 min/class, making it necessary to remove one or two slides in each lecture. Although we still struggle with the feeling that removal of any slides could leave a gaping hole in the students’ knowledge base, physical demonstrations increased student engagement and interest, and we believe this outweighs the facts they displaced. In the following sections, we share what we have learned over the last 4 years about creating and using physical demonstrations, student feedback, and impact on class environment.

## EVOLUTION OF THE “EXOCYTOSIS DEMO”

If we asked you, a biologist and teacher, to close your eyes and imagine the process of exocytosis, your head would be filled with visions of cargo-filled vesicles budding from the Golgi, motor proteins “walking” along microtubules carrying the vesicles toward the cell membrane, vesicle membranes fusing with the plasma membrane, and cargo spilling out into the extracellular environment. What do introductory biology students imagine? Typically, they think of the static image that is in the introductory biology text and shown in lecture on a PowerPoint slide: a small segment of cell membrane and a vesicle in various positions in time, before and during the process of exocytosis (Figure 1A). This does little to convey the dynamic aspects of exocytosis; therefore, it is not surprising that students often fail to understand or remember that vesicles do not magically move toward the membrane but are actively transported along microtubule tracks and that the localization and orientation of proteins in a vesicle are not random.

In fall 2004, we followed an explanation of exocytosis using the static image shown in Figure 1A with a short animation that depicted a single vesicle “floating” toward the cell membrane, fusing, and releasing its contents to the

extracellular matrix. Although some students reported this animation was useful, we found most students still envisioned exocytosis as a series of static images rather than as a dynamic process. The next year, we added a second element: a physical representation of exocytosis by using a fluorescent stretchy ball, sold as a “Halloween wig.” It was smooth and orange on the outside and could be turned inside out to expose a purple spiky surface (Figure 1B). This demonstration was short and simple. Before class, the ball with its smooth surface facing outward was loaded with white cardboard disks representing “secreted proteins.” After the exocytosis animation, the students were shown the “vesicle” and when this vesicle was turned inside out the secreted proteins spilled out across the stage and “the purple membrane-bound proteins” that had previously faced the interior of the vesicle were now facing the extracellular space. ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html#Exocytosis](http://www.researchandteaching.bio.uci.edu/lecture_demo.html#Exocytosis)). Students reported that this simple demonstration made them appreciate and remember that exocytosis was a dynamic process, helping to fill this gap in their understanding. Encouraged by this feedback, the next year the exocytosis wig was also incorporated into a second demonstration in which students served as motor proteins and carried the vesicle along microtubules to the plasma membrane of a giant cell drawn on a large plastic tarp ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html#transport](http://www.researchandteaching.bio.uci.edu/lecture_demo.html#transport)). This was designed to help students visualize movement within the cell as well as reinforce the dynamic aspects of exocytosis.



**Figure 1.** (A) Typical static slide used to explain the process of exocytosis. (B) Halloween wig vesicle, with smooth surface on outside and purple spikes representing membrane-bound proteins on inside. Cardboard disks were used to represent secreted proteins.

We have also made demonstrations that illustrate the steps that occur during a specific process. For example a garden hose with sticky ends made from Velcro can be used to illustrate a number of steps involved in cloning foreign DNA into a plasmid, including linearization, insertion, and religation ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html#cloning](http://www.researchandteaching.bio.uci.edu/lecture_demo.html#cloning)). An online library of all our faculty instruction videos, organized by biological process they address, are available at the following link ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html](http://www.researchandteaching.bio.uci.edu/lecture_demo.html)). These videos include photos of the items that were used and clips of the in-class presentation, and provide additional information, including where it occurred during the lecture and the major points to focus on.

In fall 2007, we also posted short in-class clips of our admittedly low-tech demonstrations to the high-tech world of YouTube, much to the delight of our students, some of whom were prominently featured as participants ([www.youtube.com/HHMIUCI](http://www.youtube.com/HHMIUCI)). Many students indicated that the ability to “review” the demonstrations was helpful in preparing for exams, especially for those in the back of the lecture hall where the smaller elements of some demonstrations can be difficult to see. Although our students gave the YouTube videos rave reviews, we do not believe that it is essential. It was a time-consuming endeavor, requiring videotaping, editing, and uploading.

## GUIDELINES FOR A SUCCESSFUL DEMONSTRATION

- 1) Keep it simple. Excessive detail can be distracting and even detrimental to conveying important concepts (Tversky and Morrison, 2002). Simple demonstrations are easily recalled and can be used as a mental framework that will become progressively more complex with further experience (Driver *et al.*, 1994; Ashkenazi and Weaver, 2007).
- 2) Keep it short. In our 50-min lectures, the successful demonstrations last between 2 and 6 min. When they run longer the students get restless. We found that practicing before class is important to keep the presentation short and focused.
- 3) Use items commonly found in your garage, house, or laboratory. This is beneficial to the students because everyday objects can trigger biological thoughts. As one student noted in the free-response section of a survey, “socks. i think about mitosis everytime i fold my laundry now.” Using the same item to represent a specific biological structure in different demonstrations was also useful in reinforcing recurring ideas. In our demonstrations, the orange wig was always a vesicle, and tennis balls were always free hydrogen ions ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html#buffers](http://www.researchandteaching.bio.uci.edu/lecture_demo.html#buffers); ([www.researchandteaching.bio.uci.edu/lecture\\_demo.html#respiration](http://www.researchandteaching.bio.uci.edu/lecture_demo.html#respiration)).
- 4) Include students as participants when possible. We found that inviting the students to participate in demonstrations not only engaged the class but also helped us to break down the barrier that separates us (faculty) from the students in a large lecture hall. Although we have not been able to incorporate this into every demonstration, student comments indicated that they enjoyed watching their peers and feeling that they were an integral part of

the lecture. One comment, for example, noted: “very enthusiastic and gets the class involved, great demo.”

## STUDENTS PERCEIVE DEMONSTRATIONS AS HELPFUL FOR LEARNING COURSE CONTENT

In-class iClicker polls (fall 2005, 2006, and 2007) administered after the midterm consistently showed that approximately 90% of the students rated demonstrations as helpful in understanding lecture material ( $n > 2400$  students). Each year, following the iClicker polling, we displayed the histograms of student responses and pointed out that although most found the demonstrations helpful, not everyone does. We encouraged the ~5% of students who rated the demonstrations as unhelpful to focus on their books or notes during the demonstrations. We found this increases acceptance by students who do not find the demonstrations useful as evidenced by comments such as “I assume they help a greater percentage of the class, so they should be there.”

Although the in-class rating of demonstrations was positive, we considered the possibility that the ratings could be artificially inflated because the responses were not anonymous (each iClicker is registered to an individual student). In addition, we wanted to know whether, upon reflection after the class was over and grades assigned, students still believed demonstrations had been helpful in understanding the course material. Third, we wanted to know whether student performance was correlated with their rating of the demonstrations. In fall 2007, we asked students to complete an anonymous survey after the course ended and final grades had been distributed. Responses were sorted according to class performance. To maintain their anonymity, students were directed to one of five online surveys based on their final grade (“A–F”).

Of 875 students, 320 (36%) responded to the survey, and 318 answered the following question: Please indicate how helpful you found the following in-class teaching tool: class “garage” demonstrations. The majority of respondents rated the demonstrations as “very” or “somewhat” helpful in understanding the lecture material (Figure 2A). Approximately 7% indicated they were neutral and 3% rated the demonstrations as “confusing” or a “waste of time.” The mean rating, using numerical values assigned to each category with 5 corresponding to very helpful and 1 corresponding to a waste of time, was 4 or above in all grade categories (Figure 2B). Somewhat unexpectedly, there was no correlation between rating of helpfulness and the final grade of the respondents. One possible explanation is that all students find it easier to pay attention during demonstrations, and this is equated with helpfulness. Additional research will be necessary to determine whether this is true, and if so it will be important to identify features of a demonstration, such as occurrence of something unexpected or participation of peers that increases engagement of students at all ranks.

The survey also included open-ended questions asking students what they liked about demonstrations and the class as a whole. Typical comments included, “The garage demos were awesome and helped to clarify confusing topics.” . . . and “I enjoyed how the demonstrations were very interactive. I find [sic] them to be very helpful even if I already knew the material.”

Survey results were consistent with student comments on anonymous, standardized school-administered instructor evaluations, completed by >90% of the students (807/875). Although there were no questions about demonstrations specifically, the evaluations included two open-ended questions. When asked “How can the instructor improve as a teacher?” only 1% of the students (11/807) made comments about the demonstrations, typically expressing a preference for traditional lectures, such as “not so many demonstrations, more lecturing.” In contrast, when asked, “What are the instructor’s teaching strengths?” 44% of the students (355/807) made specific positive comments about use of the demonstrations, including “Garage demos really helped to

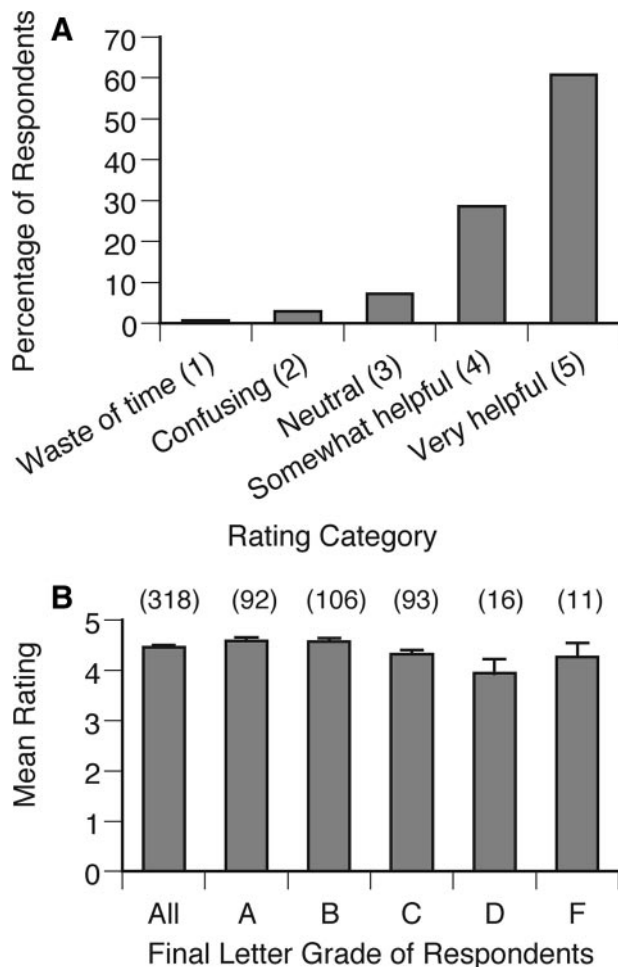
strengthen my understanding of the concepts” and “. . . presents concepts well and garage demos are amazing.”

## CLASSROOM ENVIRONMENT

The decision of faculty to try out new teaching strategies is certainly influenced by the likelihood that the technique will increase their students’ comprehension of course content. Although we are currently exploring how student performance on specific exam questions is influenced by in-class explanations supplemented by demonstrations versus static images, we have found several benefits that cannot be measured by performance on specific exam questions. The demonstrations have increased the amount of interaction between faculty and students in class, contributing to creation of a positive and active learning environment even in our lecture halls with >400 students. Of 366 students who commented on demonstrations in their end-of-quarter evaluations in 2007, 33 specifically mentioned that demonstrations contributed to the interactive nature of the class by engaging or involving the students. Representative comments included “gets the class involved, great demos” and “Her models and experiments engaged the class in the lecture.”

Some students also viewed inclusion of the demonstrations as evidence of high faculty commitment to the class based on survey comments that included “I love the demos! You can really tell that she loves what she does and puts a lot of time into preparing for each lecture,” and “A lot [sic] of time and effort can be seen.” We also found a class of unexpected positive comments on the anonymous surveys from students receiving “D’s” and “F’s” such as “Kool class, just didn’t do well because I was lazy.”

We first used garage demos in a large introductory biology course (O’Dowd and Warrior). However, demonstrations constructed and implemented with a similar philosophy have been successful when used by other instructors in classes serving different student populations. In an upper-division cell biology course and a nonmajors physiology course, both instructors (Aguilar-Roca and Williams) received very positive student feedback about demonstrations in surveys and in anonymous course evaluations. Incorporation of physical demonstrations has increased student engagement and improved attitudes in our classes, and we will continue to use them because we believe this outweighs the small number of facts they displace in each lecture. The future challenge is to determine how specific demonstrations impact student understanding of particular biological concepts and to refine them so as to maximize student learning gains.



**Figure 2.** (A) Percentage of respondents who selected each of five rating categories when asked to “Please indicate how helpful you found the following in-class teaching tool: class garage demonstrations” on an anonymous, postclass survey. Numerical values (1–5) were assigned to each category as indicated. (B) Mean rating of demonstrations determined from the numerical values assigned to each category for all respondents (ALL) and respondents sorted on the basis of final letter grade in the class. Values represent mean  $\pm$  1 SE. Total number of respondents (318) represents 36% of total enrollment (875). Number of respondents in each grade category is shown in parentheses.

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