EMBO reports

Autophagy: research topic, painting, poem, dance. . .

The combination of art and information can enhance the enjoyment and effectiveness of learning

Daniel J Klionsky

Effective teachers do no simply present information for students to learn by rote for a good grade. Rather, they provide an environment in which students can engage with course material and both learn and interpret it for their own interest and goals. With this in mind, I have spent a considerable amount of time developing an active learning format for my introductory biology course, including the presentation of information as art to address the different learning styles and needs of my students. However, I do not want to discuss my teaching methods *per se*, but rather consider the fundamental purpose of a seminar and describe how I have incorporated art to help achieve that purpose. I am sure that many scientists are skeptical of the entire concept—merging science and art to achieve an actual learning goal—but I think I can allay such doubts with a simple anecdote: If you do not see an obvious purpose behind the inclusion of music in a research presentation, consider the impact that such an approach might have on a blind student in the audience, as occurred with one of my research seminars.

> *"If you do not see an obvious purpose behind the inclusion of music in a research presentation, consider [. . .] a blind student in the audience. . ."*

The purpose of a seminar varies, of course, depending on the context, speaker, and audience, but broad goals might include: (1) bringing the audience up to date on the latest data in a field, (2) impressing the audience with how much you or your laboratory has accomplished, or (3) introducing the audience to a field of research that most attendees are not familiar with. When I give a seminar, my 20 years of teaching "introductory biology" to students might have biased me in terms of what I think my goals should be. The experience of working with undergraduates taking a required course—for some their first college-level biology class—has led me to tailor my presentations with an emphasis on simply introducing the audience to an unfamiliar topic in an engaging and memorable way. That is, most of my students do not want to know all of the fine details of my research, and they certainly do not care how productive my laboratory group has been. At best, I might be able to interest them in the topic of autophagy by highlighting a few key points, so piquing that interest and imparting some useful information has become my main aim.

Needless to say, the audience for a research seminar is not the same as that for introductory biology, but how different really are these two groups with regard to the goals of a scientific presentation? Impressing an audience with my research accomplishments might be worthwhile for me, especially if there is a potential grant reviewer paying close attention, but most people do not attend seminars for that reason. Informing the audience about the latest data in my very narrow, highly technical area of research is likewise interesting for me, but I suspect that few of the people attending a seminar want or need to know the details of everything we have been doing for the past year or more. Moreover, the literature on teaching and learning (and cognitive function) suggests that even when your goal is to convey complex information, too many details become counterproductive [1]. Furthermore, there is the entire question of how much learning can actually take place in the context of a research seminar or a classroom: It is actually quite difficult to transfer information from one person to another, which is why active learning is more effective than passive learning [2].

> *". . . it is actually quite difficult to transfer information from one person to another, which is why active learning is more effective than passive learning."*

Given the above, I decided some years ago that my goal in the classroom and in research seminars is not to attempt to convey a huge amount of detailed information to the audience. Instead, I want to introduce the audience to the broad topic of my research—macroautophagy (hereafter autophagy)—and present some of the data that I find most interesting as we attempt to understand the molecular mechanism of autophagy. At research conferences, where everyone in the audience probably is interested in the details of my research, I naturally expand on the data presentation. But in general, I try to limit the amount of actual data I present, although how to achieve the correct balance is a matter of debate. A critical issue that I try to keep in mind is that people learn in different ways and that there are many formats that can be used for

University of Michigan, Life Sciences Institute, Ann Arbor, MI, USA. E-mail: klionsky@umich.edu
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presenting information, aside from a lecture, which brings me to the point of this article.

"... people learn in different ways, and that there are many formats that can be used for presenting information, aside from a lecture."

Over the past 10 years I have taken the initiative to incorporate art into my seminars. This idea probably stemmed from my initial exposure to the 1971 short film "Protein synthesis: an epic on the cellular level", which I first saw as an undergraduate taking introductory biology at UCLA. Although I only saw the film once, it made enough of an impression on me that 25 years later, when I was teaching my own introductory biology course, I sought out a copy of the film to show in my own class. That is a rather powerful endorsement in itself; I remember very few other details from the course, but the film remains distinct in my memory. Can you ask much more of a learning tool? That experience started me thinking about ways to add my own artistic touch to the class I was teaching. At the same time, when I started my faculty position at the University of California, Davis, my assigned mentor was Dr. David Deamer, a professor in cell biology who happened to be one of the early pioneers of DNA music, in which musical notes are assigned to each base, and particular DNA sequences are converted to musical scores. So the concept of converting science to art, and the powerful example of how this could serve as a learning tool were implanted in my mind. Fast forward essentially 10 years (after the hurdles of getting a grant and renewing it, and the minor issue of tenure), I was inspired to try to convert some of the protein sequences for autophagy-related proteins into music; 20 amino acids, rather than four bases, seemed like they might yield a nicer range of possibilities. Thus, I searched for people who were engaged in this type of science–art integration and found Dr. Nobuo Munakata (Rikkyo University, Japan), a scientist and amateur musician, who was willing to work with me on several projects related to autophagy. At the same time, I had started to work with David S. Goodsell, a professor of molecular biology at the Scripps Research Institute—David is a structural biologist who is also an accomplished scientific illustrator, and for many years, I had been aware of his paintings depicting parts of the cell. So, my first projects involved a watercolor painting of selective autophagy [3], and a musical representation of the Atg9 complex [4] that incorporated some of David's artwork.

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Those first efforts were generally well received, which led me to continue along these lines, meeting with various artists and attempting to incorporate different artistic media into my research seminars. Most recently, this took the form of a choreographed representation (yes, a dance) depicting autophagy. The collaborative project that led to the dance involved four individuals: David Goodsell; Wendy Wan-Ki Lee, a professor of music at the Chinese University of Hong Kong—Wendy is a composer and pianist, and we had previously worked on a musical depiction of autophagy, which generated the solo piano piece "Macromusophagy" [5]; Peter Sparling, a professor of dance at the University of Michigan—Peter is a former member of the Martha Graham Dance Company, a choreographer and a video artist; and me—I am not much of an artist, so my main contribution was an understanding of autophagy. David, Wendy, and Peter have been kind enough to give their perspectives on the project in Sidebars A–C of this article.

One of the reasons I had previously initiated projects with David and Wendy goes back to the idea that people learn in different ways. In addition, there is substantial research on cognitive function that suggests the possible value of incorporating a multimedia approach into teaching/learning—note the distinction between teaching, which is something the instructor tries to do, and learning, which is what we actually want our students/audience members to achieve. For example, the dual-code hypothesis suggests that stimulating two channels of the brain might be more effective than an approach that uses a single mode of presentation [6]. Also, although highly controversial, background music might enhance learning [7–9]. Therefore, I wanted to utilize an approach that brought several of these media together, and a dance seemed like the obvious choice. David (Sidebar A) would provide part of the background images representing a cell, Wendy (Sidebar B) would compose some of the music, and Peter (Sidebar C) would incorporate these into a choreographed dance.

Sidebar A: David S. Goodsell

I have had several productive collaborations with Dan in the past, creating together a series of scientific illustrations depicting the processes of autophagy. This project was an exciting departure from those efforts, since the goals were not tied as tightly to depiction of the scientific details. The project came together for me during our face-to-face visit. In a rehearsal of the dance he was creating, Peter presented his vision for the piece and how it captured aspects of Dan's science using a series of scenes that depict the different moods of Wendy's music. After the meeting, I created a variety of stylized visual materials—decorative patterns based on autophagy micrographs, dark animated molecular diffusion textures, and optical microscope fields—to give Peter maximal freedom when designing the performance and video.

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To achieve this goal, the four of us met in person (Fig 1) and also communicated by videoconference and e-mail over the course of 1 year; the collaboration is described on a Web site and in a short video (http://worldclass.umich.edu/the-science-of-autophagy/ and https://www.youtube.com/watch?v=xc6KlUhWqcQ&feature=youtu.be). Much of the discussion took place between Peter and me, because we needed to decide on the overall nature of the dance performance. Peter is not a scientist, although he quickly grasped the key points that I wanted to illustrate. The lengthy discussions stemmed from two "problems": First, Peter is

Figure 1. The collaborators meet at the University of Michigan.
From left to right: Wendy Lee, Peter Sparling, and David Goodsell. Photograph credit: Daniel Klionsky.

amazingly creative, and he constantly generated new ideas for how we might present the dance—at one point even considering an underwater performance, which would have been interesting because we are depicting a cellular event after all. Second, I tend to think in terms of strictly representational art, whereas Peter is more interested in abstract art—his specialty is modern dance. Thus, even though he has done representational dance, he was intent on creating something more interesting for this unusual project. Conversely, one goal of the project was to generate a product that could be used for educational purposes, and a dance that was too abstract might not achieve that aim. At the same time as we were trying to decide on the nature of the dance, we needed to provide some direction for David and Wendy with regard to the development of the background illustrations and the music. In this case, we did not want to create these sequentially, but rather more or less simultaneously, which added another level of complexity.

"... those of us involved in the project learned a lot about how different people process information and think creatively [...] about solving the same problem."

Yet a different challenge—I mean relative to running an experiment in the laboratory, where you are largely in control of the players, the cells, and the setting—was that we needed to engage the actual dancers, choose a venue, and arrange for videotaping. Fortunately, Peter spends a considerable amount of time videotaping dances and editing the product—he is truly a master at all of this. In addition, we have excellent facilities at the University of Michigan for videotaping from multiple angles over a green screen, which would allow Peter the opportunity for extensive post-production editing. Due to budgetary considerations, and also because we wanted this project to be an educational experience, we decided to enlist as dancers the students who were enrolled in a colleague's (Professor of Dance Jessica Fogel's) dance class. I met with the students early in the process and described the basics of autophagy. Peter worked on the choreography (Sidebar C)—which I have to admit is something of a mystery to me, as is the music composition performed by Wendy (Sidebar B). I can understand how David creates his paintings (Sidebar A), but I certainly could not do it myself.

We set a date for the first presentation of the dance, which coincided with a public performance that is part of the students' course requirement. Peter had an excellent idea for the venue—the Alexander G. Ruthven Museums Building at the University of Michigan. This building was completed in 1928, and the front entry is a two-story rotunda. Peter's idea was to perform the dance on the first floor and have the audience stand on the second floor looking down, as though viewing the events through a microscope. We used this venue for two performances (Fig 2) and an encore presentation, although we had to allow seating on the first floor as well, due to the demand for tickets. A dress rehearsal of the entire dance can be seen online (https://www.youtube.com/watch?v=XODa6D3o6UA&feature=youtu.be).

Sidebar B: Wendy Lee

As a composer, I am constantly searching for innovative ways to better help organize my musical ideas. Knowing about autophagy has made me realize the numerous structural possibilities that this process could offer; my initial brainstorming in composing *Macromusophagy* involved thinking about how I could use varying degrees of harmonic dissonances, textural densities, timbral/registral contrasts, and tempo fluctuations, for example, to vividly capture my musical imagination of the various stages of this interesting scientific process that, to me, is highly emotional and expressive in nature.

This wonderful collaborative project with Dan, David, and Peter has inspired me to a take a different approach to teaching music composition. At the Chinese University of Hong Kong, where my composition students are highly proficient in the Western music tradition, I often find myself having to encourage more daring or outside-the-box compositional approaches. I have presented parts of this dance video at a faculty colloquium to my students and colleagues, and their immediate welcoming responses have convinced me that not only has this meaningful project enlightened many of my own composition and orchestration strategies, but it has also enabled my peers to observe how something in an area of study that is fact based (science) can in turn impart ideas to a discipline that is highly subjective (music).

"I am convinced—not by data, but in my own mind—that some people relate to the dance, to the visual movement of human bodies."

Was the project worthwhile and did it achieve its goals? It is always difficult to assess whether pedagogical innovations meet their intended learning goals. One reason is the

Figure 2. A scene from "How Autophagy Works", depicting an early stage of macroautophagy.
Note the projection of David Goodsell's image on the dance surface. Photograph credit: Kirk Donaldson.

limited sample size—that is, the number of performances and attendees—and another is that we are dealing with humans, which means that we cannot carry out all of the controls that are possible when working with more amenable model systems such as yeast. We certainly produced a piece of art, and we engaged a small group of student dancers who I think would agree that they learned a lot more about autophagy than they had ever anticipated when they enrolled in their class. Did the dance convey the process of autophagy to the audience? It is difficult to answer this question, but I think it is fair to say that many of the people who observed the dance performance—that is, non-scientists—learned more about this process than they would have had they not attended a performance. I think those of us involved in the project learned a lot about how different people process information and think creatively—in very different ways—about solving the same problem. Personally, I find it very interesting to work

Figure 3. A later scene from "How Autophagy Works", depicting an autophagosome that has sequestered part of the cytoplasm.
Photograph credit: Kirk Donaldson.

with artists—whether they are scientists or not—to depict my research. For example, I need to think about the best way to describe what we are doing, which is useful practice for when I want to relate this information to a scientific or lay audience. In addition, I often get asked questions that make me think about the cellular process in a new way. As an illustration of the latter point, Peter asked whether the process was directed or random—he needed to consider how to instruct the students to move—and this led to an interesting discussion among the four of us about diffusion and stochastic processes.

I also use a small segment of the dance in my seminars. I am convinced—not by data, but in my own mind—that some people relate to the dance, to the visual movement of human bodies (Fig 3), in a way that they do not relate to other modes of presentation. Autophagy is a dynamic process, and I consider it important to convey this aspect to the audience. Also, I have to admit that the entire project was a lot of fun. For example, I had never been behind the scenes at a dance

Sidebar C: Peter Sparling

A choreographer inevitably becomes a student of human behaviors. The human body has a difficult time disguising its inherent patterning regarding gesture, focus, and intentionality, despite efforts to abstract movement into an illusion of pure form in motion. So contemporary dance is caught in this delicious web of ambiguities, ranging from story-telling and dramatic portrayals in movement to crystalline formations that have no narrative but instead materialize and morph out of thin air into complex architectures made by exquisitely trained bodies. In my creative work, I run the gamut; I can too easily mix metaphors and seek correspondences anywhere and everywhere when plotting a dance work for the stage or screen. I also enjoy mixing modes of representation and media: dance, music, visual art, text, and the sciences. Eventually, the work demands focus and specificity, particularly when it is a collaborative effort involving many contributors.

Dan's proposal immediately presented to me something very specific, but suggested multiple scenarios of behaviors I could easily imagine into mini dance-dramas performed by dancers. After all, autophagy is packed with themes of deception, betrayal, intrigue, murder, cannibalism, sacrifice of the undesirable outsider, and hunter vs. the hunted. I was not interested in a dance demonstration or illustration via mime of the process of autophagy; rather, I looked for cues that could be translated into human behaviors: scenarios with their own set of motivations and intentions that would make sense in danced action. Can we read cellular activity through the lens of human behavior? After all, scientists describe the components of cells as having wills, acting or being acted upon, following cues, set on a course prompted by stimuli. As my mentor, Martha Graham, often stated about performance and its choreography: "There must be an inevitability". It seemed to me that autophagy fit the bill. I constructed a suite of dances, with acts and divertissements. I used David's colorful illustrations as prompts to costume the dancers and as set design/projected overlays to locate the action within the cell. The site itself, a rotunda, with upper balcony for aerial viewing of the action below, was perfect for the spherical shape of a cell and a downward perspective. The dancers enjoyed performing a rather exaggerated parody or vaudeville, a baroque spectacle based on science, a representation of the inner cosmos acted out by humans as they have done for centuries in ritual, dance, and theatrical presentation to assist them in understanding the wonders of the world.

performance—and have done very little along the lines of performing at all, unless we count Shakespeare's plays in high school, but let's not go there. It was energizing to see the enthusiasm of the student dancers, and I even got to participate in one of the pre-performance "psyche up" sessions—think rousing speech, group huddle, cheers.

> *"Autophagy, the musical". Now, where am I going to get those singers?"*

So, what is next on the horizon? The most obvious answer is of course: "Autophagy, the musical". Now, where am I going to get those singers?

Conflict of interest

The author declares that he has no conflict of interest.

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