Crafting a career in molecular animation

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ABSTRACT **When I first set out on a path to becoming a cell biologist, I would have never imagined that it would lead to a career in molecular animation. I had always thought I would follow a more traditional route. What happened? In this essay, I will describe the experiences that led to my decision to forge a career as an academic molecular animator, and how my work has evolved over the years. I will also provide some resources and advice for those who may be considering following a similar route.**

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SEEING MOLECULES

As a first-year graduate student at the University of California, San Francisco (UCSF), I discovered a love of microscopy. During my three rotations, I peered through microscopes to take a closer look at pathogenic yeast, the chromosomes of *Drosophila* embryos, and rapidly crawling fish keratocytes. At the end of the year, I joined Dyche Mullins' lab and settled in to study actin networks at the leading edge of motile cells. In retrospect, I think this decision was due, at least in part, to the fact that I found the actin cytoskeleton to be a beautiful structure to behold. I never got tired of looking at cells stained with fluorescent phalloidin (which is a very good thing for an actin biologist).

During my time at UCSF, the Mullins lab had weekly joint group meetings with Ron Vale's lab, whose members, for the most part, studied microtubule-based motor proteins. During my first couple of years in graduate school, I watched numerous talks given by graduate students and postdoctoral fellows about kinesin, talks that often focused on kinesin's structure and the mechanical and regulatory aspects of how it walks along microtubules. From watching all of these talks, I felt I had a pretty solid understanding of the current model of kinesin-based motility.

During one of these meetings, a graduate student presented a new animation of the kinesin motor cycle. Up until that point, I had seen only a few "realistic" animations that depicted molecules, and never within the context of a research presentation. The kinesin animation was created by Graham Johnson (now a fellow at UCSF) in collaboration with Ron Vale and Ron Milligan, and it was based on structural and biochemical data (you can view the animation online at www.cellimagelibrary.org/images/8082). The feeling I had when I watched that animation is hard to describe, but it was as though something had finally clicked in my head, a kind of "aha!" moment. I was hooked.

I started wondering why we weren't all creating molecular animations. After all, weren't all of the processes we studied dynamic and happening in three-dimensional (3D) space? Why were we relying on crude two-dimensional (2D) stick figure sketches when we could be creating animated models using structural data? I became determined to create my own animations of cellular actin dynamics and started investigating 3D animation software and courses. After some digging around, I found that, as a student at UCSF, I could take courses at San Francisco State University for free and that there was a course offered in the Spring that taught 3D animation. I was hoping to learn animation in my "off" hours, so I was disappointed to find that the animation course met every week on Fridays and took up a majority of the day. I also discovered that I needed my advisor's permission in order to register for the course. It was with no small amount of trepidation that I approached Dyche to get the needed signature. To my delight, Dyche was supportive and gave his blessing. Later, after I completed the course and had made a few animations describing research in the lab, Dyche suggested that I should continue to spend Fridays working on animations, for however long I wanted to. This was an amazing gift. Looking back, I now appreciate that Dyche's support and enthusiasm in these early years were absolutely critical for giving me the confidence (and the portfolio) that allowed me to successfully transition from being a bench scientist to a full-time animator.

Learning animation was not without its own set of challenges, however. Three-dimensional animation software is well known for

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Abbreviations used: 2D, two-dimensional; 3D, three-dimensional; GRC, Gordon Research Conference on Visualization in Science & Education; IM2, Image and Meaning 2 Conference; NIGMS, National Institute of General Medical Sciences; NSF, National Science Foundation; UCSF, University of California, San Francisco.

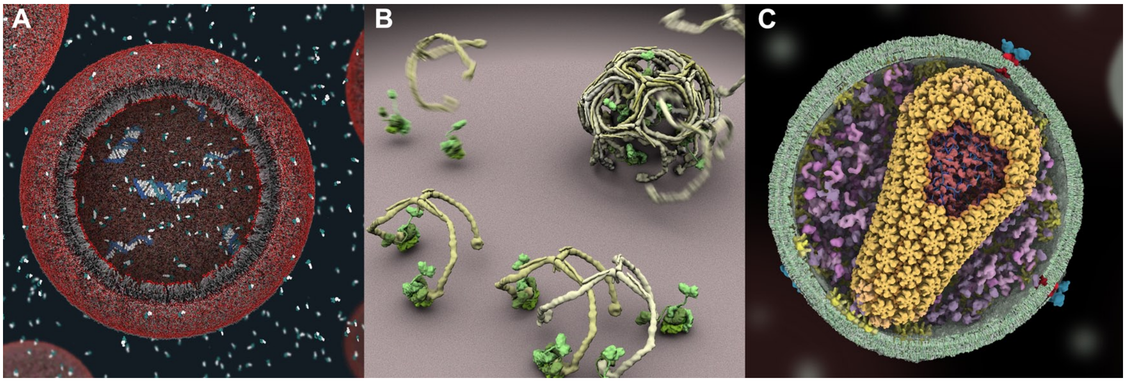

FIGURE 1: (A) An illustration of a protocell, created in collaboration with the Szostak Lab (Massachusetts General Hospital). Self-replicating nucleic acids (blue/white) are encapsulated by a fatty acid vesicle (red/gray). (B) Different steps of clathrin-mediated endocytosis are illustrated, from an animation created in collaboration with Tomas Kirchhausen (Harvard Medical School). (C) A 3D model of a HIV particle. The conical capsid (orange) surrounds viral RNA and nucleocapsid (blue/pink). The membrane (green) is studded with envelope protein (blue/red).

having a steep learning curve, requiring time and dedication to learn how to do even the most mundane tasks, as well as patience and tenacity to work through the inevitable bugs, crashes, and other technical issues. Most 3D animation packages were created for use by the entertainment industry, and the tools within them (such as modules for creating windblown hair and fiery explosions) reflect the needs of that target audience. In the course I took at San Francisco State University, I modeled living room furniture and household objects along with the other students, and later went back to the lab to use these skills to model macromolecules and cells. Part of the fun for me has always been the puzzle of figuring out how to creatively use tools that at first seem ill-suited for biology.

During my time at UCSF and the years following it, nearly all of my animations were done side by side with my lab mates and collaborators and were typically made for use in research presentations.

During these projects, I found that the process of creating the animation often gave rise to new ideas and insights that would have been difficult to gain by any other means. No other software in the lab could allow such free manipulation and viewing of multiple proteins (created using structural data or modeled from scratch), and this freedom gave us the ability to envision new possibilities and see the shortcomings of our mental models for how the biology worked. In some cases, the initial draft of the animation acted as a visual straw man that was eventually completely dismantled and rebuilt. During another collaboration, my colleagues came up with a new line of experimentation based directly on some of the questions raised during our animation project. These experiences have led me to believe strongly that animation is a powerful tool not only for communicating an idea, but also for exploring a hypothesis.

AN ANIMATION POSTDOC

As I approached my last couple of years of graduate school, I began to think seriously about a career in molecular animation. Ideally, I wanted to land a postdoc where I could do animation full-time, but admittedly, this seemed like a pipe dream. I had never heard of anyone else doing such a postdoc. Nonetheless, I talked openly and frequently about this plan with my friends, my lab mates, and my thesis committee (which earned me a couple of raised eyebrows). This unabashed broadcasting eventually paid off when a good friend told me about an unconventional postdoctoral fellowship program she had heard about, which was sponsored by the National Science Foundation (NSF) Chemistry Division and called the Discovery Corps. The Discovery Corps was a pilot program (which has, unfortunately, since been discontinued) that focused on creating new postdoctoral models combining research with outreach efforts.

While I was in graduate school, I was fortunate to have been able to attend several meetings that focused on science visualization, including the Gordon Research Conference on Visualization in Science & Education (GRC) and the Image and Meaning 2 (IM2) Conference, which was organized by science photographer Felice Frankel. At these meetings, I interacted with people from a wide range of backgrounds who were using visualization for art, education, outreach, and research. These connections were extremely valuable in linking me to a community of supportive individuals, as well as potential collaborators for future projects.

As a first step toward formulating my fellowship proposal, I reached out to Jack Szostak at Massachusetts General Hospital to inquire whether he would be interested in working with me to create animations of his lab's focus: the chemical origins of life. I also contacted individuals at the Museum of Science in Boston, connections I had made at the IM2 and GRC meetings, to explore the possibility of working with the museum to create an exhibit on how researchers study the evolution of life on Earth. After receiving two positive responses, I wrote and submitted a proposal to NSF, and, a year later, I was on my way to Boston to begin my animation postdoc.

In actuality, my postdoc started before I arrived in Boston, because I had enrolled in a 3-month crash course in Hollywood to learn a more advanced animation 3D software called Maya. With this course under my belt, I felt that I could hit the ground running. This was important, because I had only 2 years to complete more than a dozen animations, a website, and a museum exhibit.

Even with the training I had received, I was still largely figuring things out as I went along, trying to create solutions to animating tricky molecules like RNA and fatty acids (you can read about some of these challenges in a blog post I wrote for *Science* magazine's Origins series: http://blogs.sciencemag.org/origins/2009/01/visualizing-lifes-origins.html). Fortunately, my years in graduate school had taught me persistence and the ability to troubleshoot, and the project was completed successfully with the launching of a website (see http://ExploringOrigins.org and Figure 1A), the installation of an origins of life interactive kiosk in the museum, and a series of live presentations to museum visitors. Along the way, I had started to build an identity for myself as a molecular animator and to explore my options for the next steps in my career.

AN ACADEMIC ANIMATOR

Since my postdoc, I have held two faculty positions as a full-time academic animator. While my husband was completing his postdoc in Boston, I took a position as a faculty member in the Department of Cell Biology at Harvard Medical School, where I worked with fellow members of the department to visualize their research. Numerous animations came out of this time, including an animation of clathrin-mediated endocytosis (see Figure 1B and www.cellimagelibrary.org/images/12257) that I worked on with Tomas Kirchausen. In 2012, my family moved to Salt Lake City, where my husband and I both hold faculty positions at the University of Utah.

While much of my energy is spent creating and working on molecular animations for research and outreach, I have also worked on projects focused more broadly on visualization, such as the Cell Image Library (http://cellimagelibrary.org), which was initiated by the American Society for Cell Biology and funded by the National Institute of General Medical Sciences (NIGMS). The Cell Image Library houses thousands of easily searchable images and videos (including animations) of cells and cellular substructures and is a powerful and user-friendly resource for research and education.

Another ongoing major project is called Molecular Flipbook (http://molecularflipbook.org), which has been funded by the NSF. Molecular Flipbook was born out of a desire to provide researchers with an intuitive software that was made to animate molecules. The goal of Molecular Flipbook is not to make cinematic-quality animations but to have a tool that might eventually replace 2D vector illustration software (like Adobe Illustrator) for making model figures and animations for our publications and presentations. The software is free and open source, and is now available for download. I invite you to give it a try!

The most recent large-scale and public-oriented project that I've undertaken is to create a detailed molecular animation of the HIV life cycle that will highlight structural findings from the past two decades (Figure 1C). This project is funded by the NIGMS, and for it I am working together with the NIGMS Centers for HIV/AIDS-Related Structural Biology, one of which is based here at the University of Utah. I'll be launching a website called the Science of HIV (http://scienceofHIV.org) in the Fall of 2014 and will be releasing animations and videos onto the site on a regular basis until the final life-cycle animation is completed (in 2016).

In addition to these stand-alone, grant-funded projects, I've also worked on a number of other things—ranging from model figures and cover illustrations to large-scale animation projects. I've also worked on textbooks and taken a number of commissions over the past several years.

SOME UNSOLICITED ADVICE

I'm frequently asked by graduate students and postdocs about how they might pursue a career similar to my own. It's a difficult question for me to answer, because my route, although relatively direct, may not be one that is so easily replicated (due in large part to the paucity of postdoctoral opportunities like those provided by the Discovery Corps). Although I sense that there is growing interest in visualization and particularly animation within the molecular and cellular biology communities, there are, to my knowledge, very few academics who specialize in animation. Currently, many full-time scientific animators work within the private sector as freelancers or within scientific animation studios, publishing companies, journals, pharmaceutical companies, and other industries that rely on animation to communicate complex ideas to diverse audiences. That said, I also think it is likely that, met with the right talented individuals, many institutions would consider creating new positions for academic animators.

As a group, scientific animators come from diverse academic and artistic backgrounds. Some are trained as animators and artists and have then gone on to take courses in biology. Others, like me, are biologists who have learned animation. When it comes to learning animation, there are a number of options available. The best way to explore animation is to download animation software and try it out. Numerous software packages can be downloaded for free, and some are open source, such as Blender. There are countless free tutorials for any of these packages online. I've contributed a number of beginner and intermediate tutorials to the Molecular Movies website (http://molecularmovies.org) for use with Autodesk Maya.

Another more directed route to consider is enrolling in a 2-year master's program in medical illustration (see www.ami.org). In addition to teaching classical artistic methods, many programs now also focus on digital 3D animation as well. Major benefits to enrolling in these programs are that they often teach the "business side" of a career in illustration and animation and can help students with job placement or launching their own businesses as they near graduation.

No matter how you go about learning animation and illustration skills, it is critical to develop an online portfolio that allows you to show your work to would-be employers, whether in academia or industry. You might also consider volunteering to create animations or illustrations for well-established colleagues and ask that they acknowledge you clearly in their presentations and publications.

A final note: networking is crucial! There's no doubt that this is something that you, as a reader of career articles, have heard time and time again. I emphasize it here because I feel that networking has been especially important in my career, which is rooted in collaboration. I have benefited greatly from the support I've received from the larger cell biology research community and my network of friends, advisors, and colleagues, who have inspired and encouraged me over the past decade.