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Education

YouTube resources for synthetic biology education

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Abstract

Online video resources have increasingly become a common way to effectively share scientific research ideas and engage viewers at many levels of interest or expertise. While synthetic biology is a comparatively young field, it has accumulated online videos across a spectrum of content and technical depth. Such video content can be used to introduce viewers to synthetic biology, supplement college course content, teach new lab skills and entertain. Here, we compile online videos concerning synthetic biology into public YouTube playlists tailored for six different, though potentially overlapping, audiences: those wanting an introduction to synthetic biology, those wanting to get quick overviews of specific topics within synthetic biology, those wanting teaching or public lectures, those wanting more technical research lectures, those wanting to learn lab protocols and those interested in the International Genetically Engineered Machine competition.

Key words: synthetic biology; engineering biology; science communication; iGEM; science education; YouTube

Introduction

The field of synthetic biology draws on multiple scientific and engineering disciplines as it aims to make biology easier to engineer for a variety of useful purposes. While some of the keys enabling molecular biology traces back to the 1960s, the first forward-designed genetic circuits—the toggle switch and the repressilator—were both published in 2000 (1, 2).

This emerging and interdisciplinary field has generated interest from researchers, students and the general public. Online videos provide a method for researchers and science communicators to create engaging content for all of these different audiences interested in synthetic biology. In general, the proliferation of open, online videos has been a major shift in how video content can be used for education both in and out of the classroom (3). Many classrooms integrate online videos as a supplement to classroom teaching and they can be a useful tool to engage students beyond lectures and readings (4, 5). As a field that has only emerged in the last two decades, synthetic biology still has a high need for more quality content to teach and engage across the levels of technical knowledge and online videos can be a useful education tool.

Open, online videos can serve to enhance synthetic biology teaching as it does in the BioBuilder curriculum that uses lab modules to engage students (6). The video format can be useful to show animations of dynamic processes or lab skills that are difficult to teach in text-based or static visual formats. Furthermore, students and synthetic biology enthusiasts can create their own video content to further their learning and contribute to the community. The relative newness of synthetic biology may make it more favorable to student engagement as they can contribute to part of a quickly evolving field (7, 8).

Synthetic biology has already been a successful topic to engage students in biology and engineering, as made evident by the thousands of students who participate in the International Genetically Engineered Machine (iGEM) competition every year (9, 10). Video content exists for many topics within synthetic

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biology, but there has been no resource to find quality video content and sort by intended audience. A teacher or learner interested in synthetic biology currently has no resource that provides quality synthetic biology videos sorted by audience. Additionally, general video platform recommendations services can often lead to spurious videos from outrageous or malicious content producers.

To fill this need for a trusted source of educational synthetic biology videos, we created sets of playlists on YouTube which will be hosted and updated by the Engineering Biology Research Consortium (EBRC). To gather relevant, engaging synthetic biology videos, YouTube was searched by keywords ('synthetic biology', 'synbio', 'engineering biology', 'iGEM', 'CRISPR', 'genome engineering', 'genetic circuits', 'synthetic gene networks', 'artificial cells', 'synthetic cells' and 'biological engineering') based in part on keywords from synthetic biology publishing analyses by both Oldham *et al.* and Raimbault *et al.* (11, 12). Additional videos were also collected by suggestion from other researchers and educators in the field. All videos were selected for those directly related to synthetic biology, good video quality (minimal camera shaking and good sound quality) and scientific accuracy. More generally, we tried to assemble playlists (Table 1) that could be useful to a wide range of audiences interested in learning about synthetic biology and content that covered a broad range of synthetic biology topics. The following YouTube playlists are intended to be resources for all audiences interested in learning more about or teaching synthetic biology.

Playlist: synthetic biology overview

People interested in synthetic biology or some aspect of it will naturally want to understand what is meant by the term 'synthetic biology'. While the exact definition of the field is not agreed upon, there are a number of videos that can explain the basic concepts of how different synthetic biologists approach engineering biology.

This list starts with 'What is Synthetic Biology?' from the former Synthetic Biology Engineering Research Center (SynBERC), funded by the National Science Foundation. In the video, Katie Hart, then a SynBERC postdoctoral fellow, walks through the main goal of synthetic biology, which she defines as 'to engineer organisms that produce useful chemicals from inexpensive, renewable starting materials', along with implications of being able to engineer biological systems. The 'Synthetic biology, explained' video from the non-profit online magazine Grist focuses more on potential applications, the iGEM competition and futuristic possibilities with major implications in biosecurity.

Different groups give diverse viewpoints on both the overview and the potential of synthetic biology. For instance, when Goldman Sachs created a short video, titled 'Buzzwords - Synthetic Biology', explaining synthetic biology it focused on synthetic biology as a disruptive technology and its effect on economic industries. Meanwhile, the video 'What is synthetic biology to you? Charting future paths of open synthetic biology' from the Center for Research and Interdisciplinarity (CRI) highlights the viewpoints of different researchers and how they see the field evolving to tackle new research problems. Synthetic biology has caused combinations of curiosity and concern across various stakeholders as it touches on issues of human health, bioethics and fears of non-natural biotechnology. This video playlist can give the viewer a quick introduction to synthetic biology and how different groups view and define it, thus giving a good base to explore more concepts within synthetic biology.

Playlist: synthetic biology concepts

This playlist focuses on teaching core concepts within synthetic biology which can be key to understanding new trends and areas in the field. Each video in this playlist is a brief introduction to a particular aspect of synthetic biology.

Genome editing, for example, is a concept that comes up regularly both in the news and in research labs. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-associated enzymes, like CRISPR associated protein 9 (Cas9), have provided easier access to gene editing capabilities across many organisms. As CRISPR technologies have spread quickly, they have opened up numerous new applications with serious societal implications such as editing of embryos or elimination of mosquitoes that carry malaria. Organizations like Addgene, a non-profit plasmid repository, and the scientific journal *Nature* have videos explaining how CRISPR gene editing works and its applications. As powerful tools like CRISPR gene editing have captured the public imagination, there has also been significant coverage in popular media that typically don't often cover science. For example, the comedy show *Last Week Tonight with John Oliver* made its own popular and informative segment on applications of CRISPR-based technology.

To promote research findings, universities and research institutions will often also make videos to promote and explain new discoveries or developments. For instance, the Wyss Institute in Boston often makes videos on published synthetic biology work like Cas9 activation, toehold switch RNA regulators and educational kits for synthetic biology (13–16), and UC Berkeley has a video on the yeast-based production of the antimalarial drug artemisinin (17). These videos are meant to explain the concepts of new research findings for the general public.

Each of these videos provides a short explanation of one aspect of the synthetic biology field. For more in-depth exploration of any of these topics, longer lectures on many subjects can be found in the synthetic biology lectures playlist.

Playlist: synthetic biology teaching or public lectures

This playlist features longer talks from leading synthetic biology researchers who are speaking to a classroom or general public audience. These lectures provide more extensive discussions of synthetic biology and particular subfields based largely on the speaker's expertise.

One set of videos with academic faculty lecturing on their focus areas is from *iBiology* which describes its aim as 'to let you meet the leading scientists in biology, so that you can find out how they think about scientific questions and conduct their research, and can get a sense of their personalities, opinions and perspective'. They have videos with researchers across biology but have a number of videos featuring prominent synthetic biologists. Many of these videos come from speakers at the European Molecular Biology Organization (EMBO) Synthetic Biology courses for which *iBiology* has its own playlist (https://www.youtube.com/playlist?list=PLQFc-Dxlf4pRO8Ts6kzIPaoJV9KbQT1U2).

Many other videos are from faculty giving lectures for a class or giving public lecture-style talks for a general audience.

Table 1. Synthetic biology video playlists along with descriptions and Internet links

Playlist name	Description	Internet link
Synthetic biology overview	This playlist includes short videos, most 3–5 min, giving general overviews of the field of synthetic biology. Accessible for the non-scientific public.	https://ebrc.org/synbio-videos/overview
Synthetic biology concepts	This playlist includes short videos, most 5–15 min, that each focus on a particular concept, technique, or application within synthetic biology.	https://ebrc.org/synbio-videos/concepts
Synthetic biology teaching or public lectures	This playlist includes longer videos, most 30–60 min, with academic professors and synthetic biology leaders giving lectures on topics within synthetic biology for a classroom or general public audience.	https://ebrc.org/synbio-videos/teaching
Synthetic biology research lectures	This playlist includes longer videos, most 30–60 min, with academic professors and synthetic biology leaders giving seminar style lectures on their new research findings.	https://ebrc.org/synbio-videos/research-lectures
Synthetic biology in the lab	This playlist includes videos focused on basic lab protocols common to synthetic biology. Videos typically show a researcher demonstrating protocols in a lab setting while some use animations.	https://ebrc.org/synbio-videos/in-the-lab
iGEM	This playlist includes videos about the iGEM competition and videos by iGEM teams that are meant to explain their projects or engage people with synthetic biology generally.	https://ebrc.org/synbio-videos/iGEM

Depending on the context, the level of technical details can vary but each can provide a good overview of different subfields of synthetic biology.

Playlist: synthetic biology research lectures

This playlist contains research-focused lectures by leading synthetic biology researchers to groups of synthetic biology researchers. They are typically delivered as seminars at university campuses or invited talks scientific conferences. Lectures collected here provide more extensive discussions of particular projects and are often meant to give a summary of the current work happening in the lab or personal research of the speaker.

Research lectures often include presentation slides and are around 45 minutes in length with questions from the audience at the end. These talks generally assume general knowledge of synthetic biology (or related fields such as molecular biology) and provide a good overview of a lab's research at the time of the talk. They are geared toward advanced undergraduate students, graduate students, teachers and researchers looking to hear from leading synthetic biologists on new advances in the field. Online research lectures can be a particularly important tool for those unable to attend such talks in person. Overall, recorded research talks can be a compelling way to hear directly from leading researchers to learn more deeply about a specific synthetic biology subfield or a particular researcher's work.

Playlist: synthetic biology in the lab

While many of the videos in the preceding playlists can teach a lot about the field of synthetic biology generally, those interested in learning about the application of synthetic biology in the laboratory must understand the technical methods relevant to the field. Video demonstrations of laboratory protocols allow users to see how a researcher performs an experiment and can provide useful context beyond written protocols or other descriptions of a method. This video playlist includes demonstrations for many of the basic molecular biology protocols that are common to synthetic biology projects including polymerase chain reaction, DNA transformation into *Escherichia coli*, DNA extraction, agarose gel electrophoresis, restriction digests, preparation for sequencing and more.

Several videos in the playlist are from *Synthetic Biology One*, an open online course based on a first-year master's course, range from 7 to 15 min, and focus on a specific protocol that is common in a synthetic biology lab. Other videos are from Jackson Laboratory as part of its *Teaching the Genome Generation* professional development course for high school teachers. Each of these videos can be used to learn new protocols or to supplement written protocols found elsewhere. In any protocol, proper technique is important and seeing it done visually can be especially instructive for anyone who does not have a mentor or peer to show them in person. Anyone interested in performing laboratory experiments in synthetic biology should understand and follow proper safety requirements and procedures, wear appropriate personal protective equipment, and seek advice from professionals when appropriate.

Playlist: synthetic biology at iGEM

The iGEM competition brings thousands of students together each year to present on their original synthetic biology projects that they have worked on together for months. As part of their projects, students are encouraged to think about how their work can impact society and to participate in community outreach, which can result in a video as one of its products. This playlist includes videos from iGEM teams and other sources describing iGEM.

The playlist starts with 'How to Get Started in Synthetic Biology' from Kim de Mora at the Museum of Science in Boston that covers iGEM's history and mechanics as well as several project examples. It is followed by a 2016 interview with iGEM Foundation president Randy Rettberg that gives another overview of iGEM along with some context of its place in the synthetic biology field.

Videos from iGEM teams often aim to give an overview of iGEM or that team's project. Since teams at iGEM choose a wide

range of project types that span the definition of synthetic biology, the team videos provide a look at the diversity of ways synthetic biology can be used. One particularly unique project was *Biota Beats* (18) from the EMW Street Bio iGEM 2016 team that involved sampling of human microbiomes, tracking of bacterial growth and digital conversion of growth data to an audio file that can be listened to as music. An example of the kind of presentations that happen at the annual iGEM competition can be seen with the iGEM Aachen 2014 team's presentation on their novel biosensor system that they called *Cellock Holmes*. In addition to videos explaining synthetic biology topics and projects, many iGEM teams make fun videos such as music video parodies. Some examples include 'iGEM Style' as a parody of 'Gangnam Style' by artist PSY and 'Protocols' as a parody of Lady Gaga's 'Applause'.

Overall, the iGEM playlist gives an idea of what the competition is about and the enthusiasm that the student teams bring to their projects. New iGEM participants and those interested in what iGEM teaches can learn from this playlist collection.

Conclusion

As synthetic biology continues to mature as a discipline, it is important for researchers and the general public to be able to keep up with developing trends and technologies. While these playlists are not exhaustive collections of video resources for teaching or learning synthetic biology, they represent a strong starting point to capture a wide breadth of useful content for interested individuals at any level in synthetic biology.

The video playlists will be maintained and updated on an ongoing basis by the Engineering Biology Research Consortium through their Synthetic Biology Education Working Group. The authors would welcome suggestions for additional videos to incorporate into the playlists, or new playlists all together, and can be submitted to education@ebrc.org. This video playlist collection will be periodically updated to help provide a destination for people of all levels of interest in synthetic biology to find free and engaging video content.

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