

Design Guidelines and Empirical Case Study for Scaling Authentic Inquiry-based Science Learning via Open Online Courses and Interactive Biology Cloud Labs

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H. Riedel-Kruse

Stanford University

This supplement contains the screen shots from the 6th course offering.

Interactive Microbiology and F x

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Interactive Microbiology and Foundations of Scientific Practice

Go to Course

Course topic: Natural and Social Sciences

OVERVIEW

Welcome to the Stanford Online Mini-Course "Interactive Microbiology and Foundations of Scientific Practice." In this course you will learn about some fascinating phenomena at the microscopic living world - and at the same time practice the key aspects of the scientific method.

Also, note that the total number of participants is restricted for each session. If a session is already full - please try to sign up for another one.

UPCOMING SESSIONS:

Session 7: August 30 - September 4

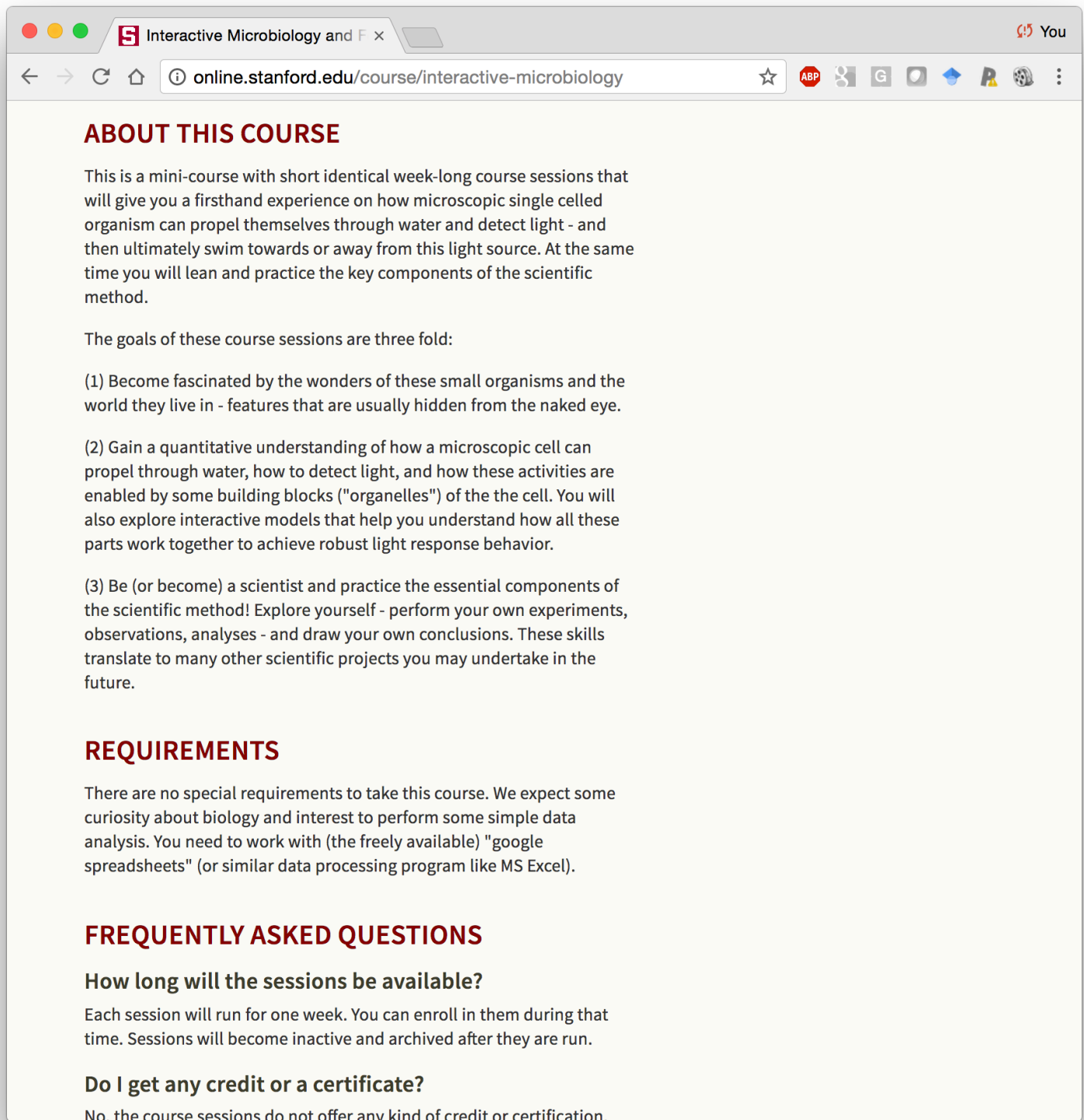
Session 8: September 6 - September 11

Session 9: September 13 - September 18



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ABOUT THIS COURSE

This is a mini-course with short identical week-long course sessions that will give you a firsthand experience on how microscopic single celled organism can propel themselves through water and detect light - and then ultimately swim towards or away from this light source. At the same time you will learn and practice the key components of the scientific method.

The goals of these course sessions are three fold:

- (1) Become fascinated by the wonders of these small organisms and the world they live in - features that are usually hidden from the naked eye.
- (2) Gain a quantitative understanding of how a microscopic cell can propel through water, how to detect light, and how these activities are enabled by some building blocks ("organelles") of the cell. You will also explore interactive models that help you understand how all these parts work together to achieve robust light response behavior.
- (3) Be (or become) a scientist and practice the essential components of the scientific method! Explore yourself - perform your own experiments, observations, analyses - and draw your own conclusions. These skills translate to many other scientific projects you may undertake in the future.

REQUIREMENTS

There are no special requirements to take this course. We expect some curiosity about biology and interest to perform some simple data analysis. You need to work with (the freely available) "google spreadsheets" (or similar data processing program like MS Excel).

FREQUENTLY ASKED QUESTIONS

How long will the sessions be available?

Each session will run for one week. You can enroll in them during that time. Sessions will become inactive and archived after they are run.

Do I get any credit or a certificate?

No, the course sessions do not offer any kind of credit or certification.

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FREQUENTLY ASKED QUESTIONS

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No, the course sessions do not offer any kind of credit or certification.

Do the course sessions include the ability to earn a Statement of Accomplishment?

Yes.

Do you have an attendance limit - and what should I do if the course is already full?

Yes - we do have a limit of how many participants we can accommodate in any give course offering. If you first choice is already full - then sign up for another one. In case of very high demand - we will make more course offerings avaiable in the near future.

COURSE STAFF

Ingmar Riedel-Kruse

Assistant Professor, Bioengineering Stanford

Instructor

Zahid Hossain

Graduate Student, Bioengineering and Computer Science

Instructor

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Welcome to Engineering's BioLab!

Interactive Microbiology Session 6

Resume Course

Course Updates and News

AUGUST 15, 2016

WELCOME

In this mini-course you will learn about how microscopic single celled organisms can propel themselves through water and react to light, by engaging in key practices of science inquiry like experimentation or data analysis.

Here is some more information on the course itself:

1. This course is very unique as it includes a real time interactive online microscope, i.e., you can do experiments with single celled organisms over the web. And while we did significant beta testing - some challenges may have gone undetected - this is really at the edge of current research. So [if you encounter unsolvable technical challenges - poste it on the discussion forum with the header "Online course problems"](#) - and we try to help.
2. You will have to work with Google Sheets (<https://www.google.com/sheets/about/>) to produce meaningful visualizations from the raw data of the experiments. In order to do so, make sure you have an account with Google that allows you to open and edit spreadsheets that you can download from the experiments. We will teach you the basics for creating data visualizations within Google Sheets, or use functions to calculate relevant measures.
3. The course consists of reading passages, activities and quizzes. You will run experiments, create data visualizations, watch videos, and do basic calculations. Throughout the course, you will be asked questions that require an open-ended response, that ask for your feedback on the technology and instruction, or that assess your understanding of both the biology and the data analyses, and multiple choice questions. Doing the activities and answering quizzes counts towards your passing grade. You need 50% for a pass.
4. In case something with the technology doesn't work, you have questions about either the course material or the logistics, or you want to share your thoughts and feedback, we encourage you to use the discussion page, besides sending us an email.
5. The course will take you about 4 hours (based on feedback from previous participants - some took half the time - some took twice as long).

Let's get started!

Important Course Dates

Course End
1 year ago - Aug 28,
2016

This course is archived, which means you can review course content but it is no longer active.

Today is Jul 17, 2017
(12:38 UTC)

Course Handouts

Navigation | Make some first

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Engineering: BioLab Session 6 Interactive Microbiology Session 6

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Bookmarks

#1: Cells under the microscope

Make some first observations about microscopic organisms!

Activity

#2: Stimulate Euglena with light

#3 Qualitative post-experiment data analysis

#4: Euglena structure and control feedback for robust phototaxis

#5: Quantitative data analysis

#6: The scientific method

#7: Summary and feedback

Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Navigating the course

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THE BASIC ASPECTS OF THIS PLATFORM

Welcome to Lagunita, Stanford University's version of Open edX. Are you new to Lagunita? Click on the button below to learn how to navigate the course software.

How Do I Find My Way Around This Course?

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#1: Cells under the microscope

Make some first observations about microscopic organisms! Activity

#2: Stimulate Euglena with light

#3 Qualitative post-experiment data analysis

#4: Euglena structure and control feedback for robust phototaxis

#5: Quantitative data analysis

#6: The scientific method

#7: Summary and feedback

Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Introduction

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WELCOME

This mini-course is about how single-celled organisms detect and respond to light, and the biophysical principles that govern this behavior. For this course, instead of using a traditional lecture-based approach, we will use a novel interactive online microscope that allows you to run your own live experiments on single celled micro-swimmers. You will be able to collect and analyze your own data and use this data to evaluate different models of these micro-swimmers; you will also learn how to use Google Sheets to produce meaningful visualizations from your raw data to support your analysis and inference.

We have interwoven reading passages, activities and quizzes into one course. Doing the activities and answering quizzes counts towards your passing grade. You need 50% in order to pass. Completing the course typically takes between two and four hours (although some previous participants have explored more deeply and taken significantly longer - this is up to you).

While we did significant beta testing with this new online microscope, some challenges may have gone undetected - we are really operating at the edge of current research! If you encounter unsolvable technical challenges, please send an email to euglena.cloudlab@gmail.com with the header "Online course problems," and we will try to help.

To navigate the course, press the "Next" button at the bottom of each page. When a section is finished, you can select the next one from the left panel. You can self-generate a "Statement of Accomplishment" after you have completed the course.

Sit back, relax, and enjoy! We are excited to take you on this journey!

Ingmar Riedel-Kruse, Course Instructor
Assistant Professor of Bioengineering, Stanford University

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Bookmarks

#1: Cells under the microscope

Make some first observations about microscopic organisms! Activity

#2: Stimulate Euglena with light

#3 Qualitative post-experiment data analysis

#4: Euglena structure and control feedback for robust phototaxis

#5: Quantitative data analysis

#6: The scientific method

#7: Summary and feedback

Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Pre-course survey

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LET'S START WITH SOME PRE-COURSE QUESTIONS!

These questions will give you a flavor of what to expect in the course. You will get points for answering them, independently of whether you get the answers right or not. Please do not look up the answers - we would like to assess your pre-course knowledge.

STAFF DEBUG INFO

HOW BIG ARE EUKARIOTIC CELLS? (1 point possible)

Eukaryotic cells are cells that have a nucleus. For example, all cells of animals, plant, and fungi are Eukaryotes. How big are these Eukaryotic cells typically?

Your response must be between 1 and 10000 words.

Submit

Save

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HOW DO YOU THINK SINGLE-CELLED ORGANISMS SENSE AND NAVIGATE THEIR ENVIRONMENT?

(1 point possible)

Explain:

Your response must be between 1 and 10000 words.

Submit

Save

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HOW FAST ARE EUKARYOTIC CELLS IN THE POND? (1 point possible)

When you look at pond water under the microscope, you can often see many cells swimming around. What do you think is a typical speed of these cells?

Your response must be between 1 and 10000 words.

Submit

Save

Text | Make some first observa x

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Help

HOW FAST ARE EUKARYOTIC CELLS IN THE POND? (1 point possible)

When you look at pond water under the microscope, you can often see many cells swimming around. What do you think is a typical speed of these cells?

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

WHAT ARE THE MAIN COMPONENTS OF THE SCIENTIFIC METHOD? (1 point possible)

Explain:

Your response must be between 1 and 10000 words.

Submit

Save

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How much do you agree with the following statements? (1 - totally disagree; 5 - neutral; 9 - strongly agree)

(4 points possible)

Science is interesting.

I know what it's like to be a scientist.

Ordinary people can be scientists.

I can imagine myself as a scientist.

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SHOW ANSWER

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Help

I know what it's like to be a scientist.

Ordinary people can be scientists.

I can imagine myself as a scientist.

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SHOW ANSWER

SUBMISSION HISTORY

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PRE-COURSE SURVEY

Please take the following additional general pre-survey for Stanford online courses. This is voluntary, but would significantly help us to improve our course in the future. Thanks!

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The survey will open in a new browser tab or window.

Begin Survey

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English

Welcome to Stanford Online Mini "Interactive Microbiology and Foundations of Scientific Practice" taught by Professor Riedel-Kruse!

This is the official course survey which we strongly encourage you to complete.

How many hours are you planning to spend on this course? (please enter a number)

Do you have any prior experience with the course topic?

☐ Yes, I do.

☐ No, I don't.

How many open online courses have you started before this one? (please enter a number)

How many open online courses have you finished before this one? (please enter a number)

Next

Text | Make some first observa xStanford Pre-Course Survey xYou

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Stanford|English

Pick the statement that **best** describes your learning intentions for the course:

☐

I intend to learn about all of the topics

☐

I intend to learn about some of the topics and I **know** which ones

☐

I intend to learn about some of the topics but I **don't know** which ones

☐

I am not sure

Next

Next

Text | Make some first observa x

Stanford Pre-Course Survey x

You

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English

What is your gender?

☐ Male

☐ Female

☐ Other

In what year were you born? (e.g. 1985)

In which country were you born?

Next

Text | Make some first observa xStanford Pre-Course Survey xYou

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Stanford |English

What is the highest level of schooling you completed?

☐ Doctorate/Ph.D.

☐ Masters

☐ Professional

☐ Bachelors

☐ Some College

☐ Associate

☐ Secondary/High School

☐ Middle school/Jr. High

☐ Elementary

☐ None

Next

Text | Make some first observa xStanford Pre-Course Survey xYou

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Stanford|English

Which best describes your current employment status?

☐

Full-time employed

☐

Part-time employed

☐

A high school (or younger) student

☐

An undergraduate

☐

A graduate student

☐

Unemployed

☐

Retired

Next

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English

How old are you?

Under 13

13-17

18-24

25-34

35-44

45-54

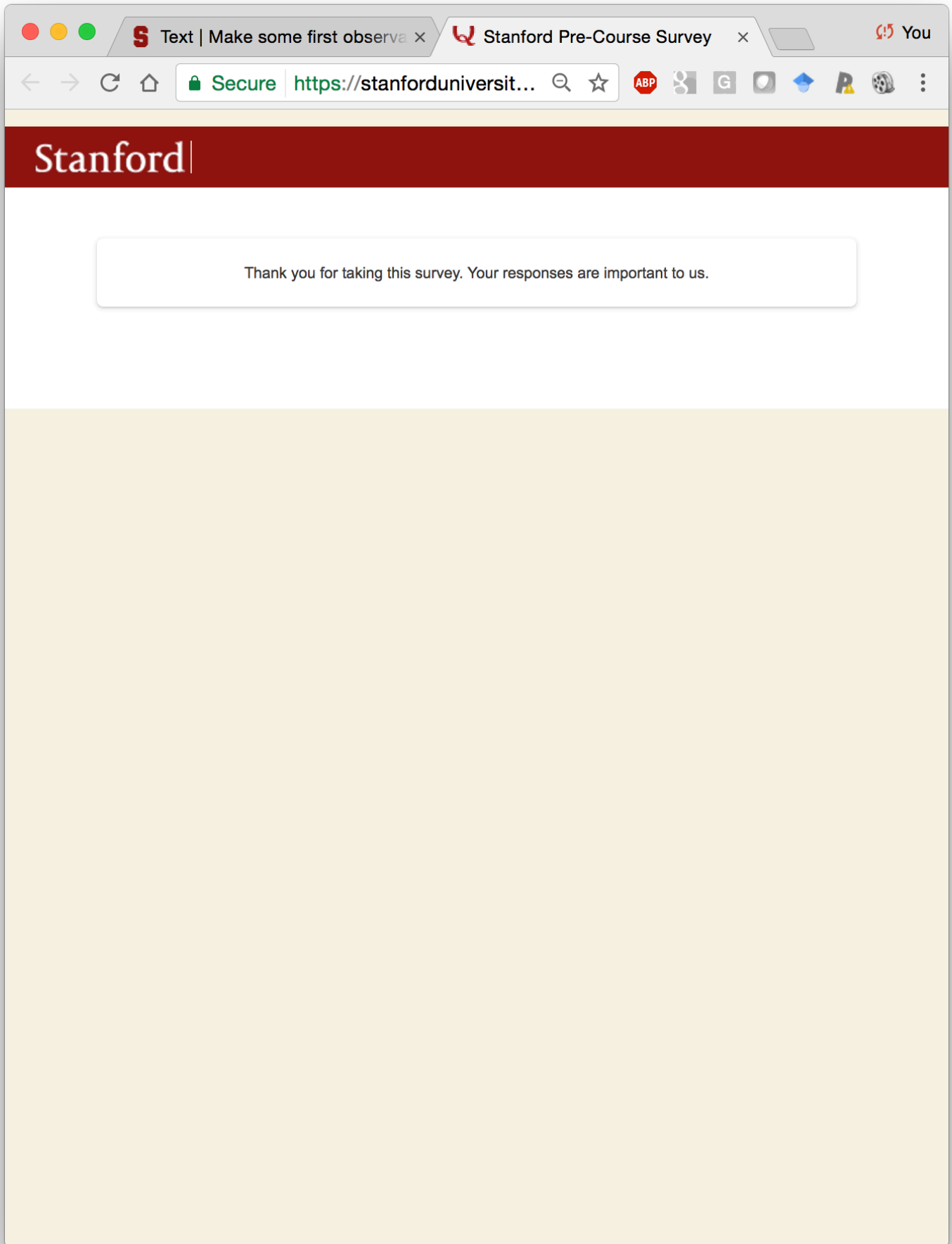
55-64

65 or older

Would you describe yourself as

- ☐ White, Caucasian
- ☐ East Asian
- ☐ South Asian
- ☐ Middle Eastern
- ☐ Black, African American
- ☐ Hispanic, Latino
- ☐ Native American
- ☐ Pacific Islander
- ☐ Other

Next



Bookmarks

- ▼ #1: Cells under the microscope

Make some first observations about microscopic organisms!
Activity 

- ▶ #2: Stimulate Euglena with light

- ▶ #3 Qualitative post-experiment data analysis

- ▶ #4: *Euglena* structure and control feedback for robust phototaxis

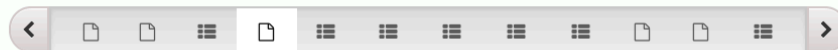
- ▶ #5: Quantitative data analysis

#6: The scientific method

- ▶ #7: Summary and feedback

► Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Access the online microscope

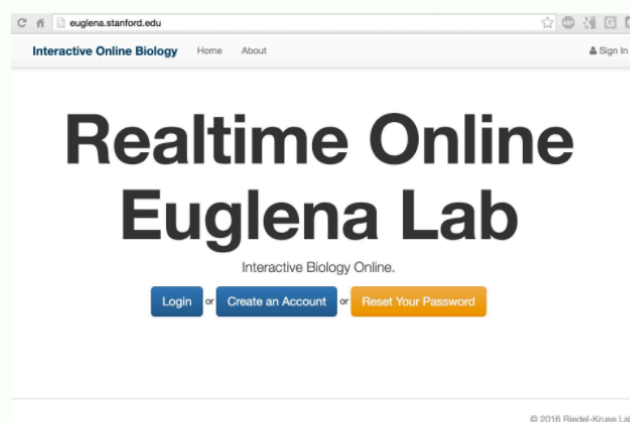
[VIEW UNIT IN STUDIO](#)

Bookmark

THE REALTIME ONLINE MICROSCOPE

So - what do microscopic cells look like? We have prepared a **real-time online microscope** so that you can see for yourself!

Please go to the following link: <http://euglena.stanford.edu/>. The login page shown below should open in a separate tab.



(Image copyrights: see end of course).

Create a username and password that are **identical (!!!)** to the ones that you used to sign up for Lagunita.

In terms of browsers, Firefox and Chrome should work best. Ideally, you should have a download speed of 50 Mbps or more, but the software should still work with less.

NOTE 1: When working with the online microscope and the corresponding analysis tools, you should switch tabs back and forth between this online course and the online microscope.

NOTE 2: Ideally, have only one window with the online microscope open at a time.

NOTE 3: If you have problems accessing this website, check that you have only one browser window with the online microscope open. If you still have problems, please post on the discussions page or email us so we can address the issue and improve the course.

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🔖 Bookmarks

#1: Cells under the microscope

Make some first observations about microscopic organisms! Activity

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Statement of Accomplishment

Help

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Looking into the online microscope

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🔖 Bookmark

INSIDE THE REALTIME ONLINE MICROSCOPE

After you have created your user account and logged in, you should see an **overview page** (left image below) that allows you to access one of multiple online microscopes. Press the main blue **Live Join** button at the top. This will lead you to one of the online **microscope pages** (right image below). Watch and enjoy!

After one minute, the online microscope will turn off automatically to let other potential users in. You can enter again right away if a microscope is available. Note that you can enter via the "Live Join" button at the top as before, which leads you to the next best available microscope, or you can choose a specific microscope by pressing any of the blue "Live" buttons further down.

(Note: Not all of the online microscopes necessarily have the same magnification, but you can use any microscope for the activities throughout the course. The density of cells and their behavior may also differ between microscopes, although most of the time it should be about similar for all of them. We encourage you to try more than one microscope.)

🔍 euglena.stanford.edu/realtime/

Interactive Online Biology Home About

Updated: Mon Jul 04 2016 23:44:36 GMT-0700 (PDT)

Log out from Realtime Online Microscope

No test experiments in queue or any microscope. Click To Join.

Submit Pre-Programmed Experiments to Your Available Online Microscopes

No test experiments in queue. Click To Join.

Choose Map: No file chosen

Reconnect to Latest Test Price

Available Realtime Online Microscopes - Choose One

Note: You can only run one test experiment at a time

🔍

🔍

🔍

🏠 Sign Out

🔍 euglena.stanford.edu/realtime/

Interactive Online Biology Home About

eug2 Time Remaining: ~25 seconds.

Angle: 0 degs Intensity: 0.00

🔍

🔍

🏠 Sign Out

(Image copyrights: see end of course).

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Ease of use microscope
(1 point possible)
How easy was it for you to create a login and get access to the online microscope? (Note: Even if you are struggling right now, keep going the next few pages - there will be alternatives to help you.)

☐ This was easy.

☐ I struggled a bit - but eventually figured it out.

☐ I still don't know how to do it - even though I tried to follow all the provided explanations.

?

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Online Microscope Quality | M x

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#5: Quantitative data analysis

#6: The scientific method

#7: Summary and feedback

Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Test question online microscope quality

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Online Microscope Quality
(1 point possible)
How is the frame rate quality of the online microscope?

☐ Video is smooth, video rate is good, and I saw movement of cells on the screen.

☐ Video is OK - I saw the cells moving, but occasionally the frame rate drops and there are mild glitches.

☐ Video rate is poor - I can occasionally see some images, but it is so bad that it is nearly impossible for me to use it.

☐ The microscope page loaded, but the frame where the video should be is empty.

☐ The microscope page did not load at all - I was in the overview page and tried, but after more than 2 minutes I did not get any further.

☐ I did not get beyond the login page - either the site did not load, or I tried to create a user account but was not successful.

?

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SUBMISSION HISTORY

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STAFF ANALYTICS INFO

OPTIONAL: WHAT BROWSER AND VERSION DO YOU USE?
(for example "Google Chrome - Version 51.0.2704.103 (64-bit). Independently of whether the online microscope works well for you or not, this will help us to identify potential technical challenges so we can help other users in the future.

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

Online Microscope Quality | M x

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Accomplishment

Help

account but was not successful.

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OPTIONAL: WHAT BROWSER AND VERSION DO YOU USE?

(for example "Google Chrome - Version 51.0.2704.103 (64-bit). Independently of whether the online microscope works well for you or not, this will help us to identify potential technical challenges so we can help other users in the future.

Your response must be between 1 and 10000 words.

SubmitSave

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OPTIONAL: WHAT IS THE DOWNLOAD SPEED OF YOUR INTERNET CONNECTION?

You can figure this out using the website "http://www.speedtest.net/". Enter, for example, "14.95 Mbps". Independently of whether the online microscope works well for you or not, this data will help us to identify potential technical challenges so we can help other users in the future.

Your response must be between 1 and 10000 words.

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#1: Cells under the microscope

Make some first observations about microscopic organisms! Activity

#2: Stimulate Euglena with light

#3 Qualitative post-experiment data analysis

#4: Euglena structure and control feedback for robust phototaxis

#5: Quantitative data analysis

#6: The scientific method

#7: Summary and feedback

Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Alternative to real time live

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Bookmark

ALTERNATIVES TO THE ONLINE MICROSCOPE IN CASE YOUR CONNECTION IS BAD

(If you are satisfied with the speed and quality of your online microscope, please continue on to the next page.)

For satisfactory streaming of the online microscope, a download speed of 50 Mbps or higher is ideal. You can figure out your download speed using a website such as <http://www.speedtest.net/>. In case you are not able to get a faster connection or have other problems, we will now show you how you can download the microscope movies to your hard drive and analyze them offline.

STAFF DEBUG INFO

VIEWING AND DOWNLOADING YOUR EXPERIMENTAL DATA

Besides watching the experiments live and in real time, there are two other ways for you to look at your experimental data after the experiment has finished:

(1) The online movie viewer allows you to replay your previous experiments in the browser

(2) A set of downloadable files contains that movie and various additional quantitative data, such as the speed and position of the majority of Euglena, the direction of light stimuli, etc. for your previous experiments.

Go to the overview page of your online microscope <http://euglena.stanford.edu/account/> (we recommend you just keep that tab open). Scroll down and find a list of all your previously executed experiments (it may take 2-3 minutes after you finished an experiment before it shows up here, though typically it is much faster. You can try refreshing your browser page):

All Experiment Data

	Submission Time	Microscope Name	Tag	Status	Experiment ID
View Download	Sun Jul 03 2016 06:44:46 GMT-0700 (PDT)	eug0	live	finished	577916cae53a112626cc01af3
View Download	Sun Jul 03 2016 06:43:33 GMT-0700 (PDT)	eug1	live	finished	5779168563a112626cc01af2
View Download	Sun Jul 03 2016 06:42:17 GMT-0700 (PDT)	eug2	live	finished	5779163963a112626cc01af1

(Image copyrights: see end of course).

Each row is a different experiment. Select "View" and a movie viewer will open in a new tab. Select "Download" and a complete data set will be downloaded to your hard drive. If you unpack that file, you will find two mp4 files - one is raw and the other has various information overlaid. You can then watch your movies locally. For the following activities you should work with the movie that has various overlays (such as a scale bar).

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Help

Go to the overview page of your online microscope <http://euglena.stanford.edu/account/> (we recommend you just keep that tab open). Scroll down and find a list of all your previously executed experiments (it may take 2-3 minutes after you finished an experiment before it shows up here, though typically it is much faster. You can try refreshing your browser page):

All Experiment Data

	Submission Time	Microscope Name	Tag	Status	Experiment ID
View Download	Sun Jul 03 2016 06:44:46 GMT-0700 (PDT)	eug0	live	finished	577916ce63a112626cc01af3
View Download	Sun Jul 03 2016 06:43:33 GMT-0700 (PDT)	eug1	live	finished	5779168563a112626cc01af2
View Download	Sun Jul 03 2016 06:42:17 GMT-0700 (PDT)	eug2	live	finished	5779163963a112626cc01af1

(Image copyrights: see end of course).

Each row is a different experiment. Select "**View**" and a movie viewer will open in a new tab. Select "**Download**" and a complete data set will be downloaded to your hard drive. If you unpack that file, you will find two mp4 files - one is raw and the other has various information overlaid. You can then watch your movies locally. For the following activities you should work with the movie that has various overlays (such as a scale bar).

STAFF DEBUG INFO

Does the downloaded movie work for you?

☐ I was able to find the two videos among the downloaded files. I can play these videos, and I see cells moving. (Success! You can continue with the course.)

☐ I can watch the videos but I do not see any cells. (In this case you should generate more experiments and download them. If the problem persists, contact us.)

☐ I am not able to download or unpack the files. (In this case you should contact us.)

?

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Organisms Under the Microscope

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#7: Summary and feedback

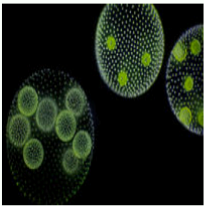
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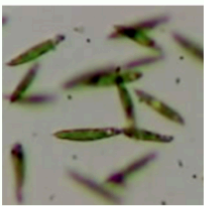
#1: Cells under the microscope > Make some first observations about microscopic organisms! > Some warm up questions...

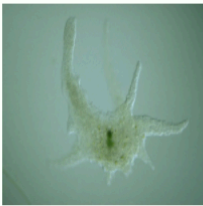
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ORGANISMS UNDER THE MICROSCOPE







(A)

(B)

(C)

(Image copyrights: see end of course).

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Organisms under the Microscope

(1 point possible)

Which of the following organisms above did you see under the microscope?

☐ A)

☐ B)

☐ C)

?

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How long is a Euglena cell? | 1 x

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Statement of Accomplishment

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< >

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How long is a Euglena cell?
(1 point possible)
What is the typical length of a Euglena? Estimate the length of a cell based on the scale bar that you see on the online microscope.

Write your estimate of the size of Euglena in micrometers:

?

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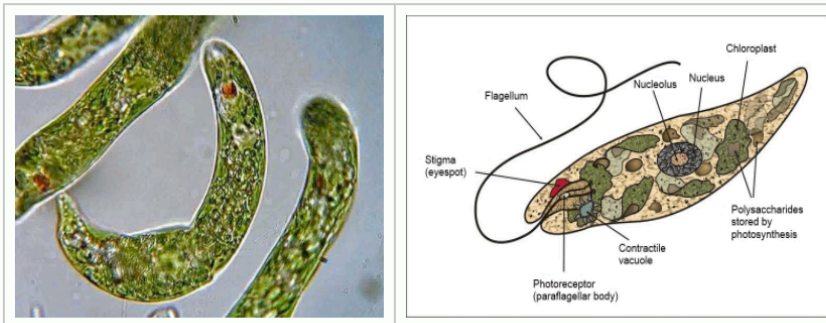
#1: Cells under the microscope > Make some first observations about microscopic organisms! > Euglena structure, ecology, and photo-taxis

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EUGLENA STRUCTURE AND FUNCTION

What you saw under the microscope was the single-celled organism *Euglena gracilis*, or *Euglena* for short. *Euglena* lives in ponds, where the cells swim around very actively.



(Image copy rights: see end of course).

Euglena are very important for ecosystems as well as for humans: they can be grown in large quantities and then used for fuel and food production. They can also serve as an environmental indicator; for example, you can take a sample of pond water and look under the microscope at whether Euglena behaves abnormally, which can provide an easy indicator of whether the water is polluted.

Looking at the pictures above, do you notice some interesting cellular structures (organelles) in comparing the photograph and the drawing? Do you see the red spot or the long line attached to the cell? What do you think these structures are used for?

Euglena has an elongated green cell body containing green chloroplasts that perform photosynthesis, a long slender flagellum that beats and propels the cell through fluid, and a red eye spot that detects where light is coming from. In this course, we want to explore with you how these cellular structures interact and thereby facilitate Euglena behavior.

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Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Course goal - understand Euglena phototaxis / be a scientist

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THE SPECIFIC GOALS OF THIS MINI-COURSE

(1) To become fascinated by the wonders of these small organisms and the world they live in, features that are normally hidden from the naked eye.

(2) To learn how a microscopic cell can detect environmental stimuli and move through water, and how these activities are enabled by the cellular structural building blocks ("organelles").

(3) To learn how to analyze quantitative and noise data in order to answer specific research questions that foster your understanding of the biology at play.

(4) To get better at the essential practices of scientific inquiry: observing novel biological phenomena, designing and running experiments motivated by specific research questions, collecting and analyzing your own data, and drawing conclusions from that data. These practices translate to many other scientific projects you may undertake in the future.

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Statement of Accomplishment

#1: Cells under the microscope > Make some first observations about microscopic organisms! > Summary

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SECTION SUMMARY

In this section, you have observed single-celled micro-organisms called Euglena using an online microscope.

In this course you will perform your own scientific investigations (observing, performing experiments, analyzing and interpreting your data, exploring models) and gain a deeper understanding of how Euglena, and likely many other micro-organisms, behave in their natural environment.

Congratulations - You finished section #1!

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How much time did you spend on section #1?
(1 point possible)
Time in minutes:

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Now go to section #2 (select from the left side of the screen).

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#2: Stimulate Euglena with light > Run your own experiment! > Unit overview

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SECTION OVERVIEW

In this section, you will perform experiments to investigate how *Euglena* respond to light. The online microscope provides you with an interface to apply light stimuli to the cells in real time. You can change the direction and intensity of the light that reaches the cells.

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Statement of Accomplishment

#2: Stimulate Euglena with light > Run your own experiment! > Guess - what happens to Euglena with light

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YOUR HYPOTHESIS: (1 point possible)

Before doing an actual experiment: What do you think will happen if you shine light onto Euglena?

Your response must be between 1 and 10000 words.

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Stimulating euglena with light

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Statement of Accomplishment

#2: Stimulate Euglena with light > Run your own experiment! > Stimulate Euglena with light!

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STIMULATING EUGLENA WITH LIGHT IN REAL TIME

When you used the online microscope before you just observed Euglena. Now, you will start actually interacting with these cells by applying directional light stimuli.

In the upper right corner there is a virtual joystick (see picture below). You can drag the blue button around with your mouse pointer. This joystick actually controls the intensity of four LED lights that are located at the four sides of the microscope (up, down, left, and right). Note also the yellow intensity indicators on the four sides of the microscope view, which tell you **where the light is coming from**. In the image shown below, the bars at the top and right are highlighted in yellow, therefore the light comes from the upper right. Note that **the joystick points into the direction of which LEDs are turned on** and not in the direction the light is shining - again see image below! These lights might influence Euglena behavior. Go back again to the online microscope (<http://euglena.stanford.edu/account/>) and **PLAY AROUND** with this joystick. Observe whether and how Euglena respond to your light stimuli.

eug0 Time Remaining:~30 seconds.

057

53

Angle: 47 degs
Intensity: 0.78

(Image copyrights: see end of course).

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Ease of use Joystick and light stimulus
(1 point possible)
Could you operate the joystick and did you see the yellow bars (light indicators) change on the four sides? (Note: Even if you are struggling right now, keep going - there will be alternatives to help you on the next page.)

☐ This was easy.

☐ I struggled a bit but eventually figured it out.

☐ I still don't know how to do it - I am having technical difficulties due to the browser, bandwidth or something else).

?

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#2: Stimulate Euglena with light > Run your own experiment! > Batch mode

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ALTERNATIVES TO JOYSTICK LIGHT STIMULATION IN CASE OF TECHNICAL DIFFICULTIES ("BATCH MODE")

Here is a way of running the experiment offline if you have problems with the online joystick. (If you don't have problems with the online joystick, just go ahead to the next page - you do not need anything on this page to complete the course.)

You can pre-define a stimulus protocol offline in form of a simple script that indicates which of the four LEDs should be on for how long and when. You can then submit this experiment, wait until it is executed, and download the data and a video for further analysis a few minutes later. This is called "batch mode."

In order to use batch mode, you first need to generate a .csv file using, for example, Excel or Google Sheets (see https://www.google.com/sheets/about/). This file needs to follow exactly(!!!) the following format (see example below):

- All yellow fields need to have the exact wording shown below; all fields in blue you can change (the color does not matter).
- In the fields B1 and B2 you can enter single word descriptors; this does not affect your experiment.
- Column A starting from row 5 are the timings in units of milliseconds, which are ordered from 0 to 60,000. An experiment is always 60 seconds (60,000 milliseconds) long.
- Columns B-E are the intensities of each of the four LEDs in arbitrary units ranging from 0 (light off) to 100 (maximal light intensity on).
- As shown, start with a row [0 0 0 0 0] and end with the row [60000 0 0 0 0]
- You can then add rows with times in between 0 and 60,000 with various LED intensity values between 0 and 100.
- When finished, save this file in .csv format locally.

	A	B	C	D	E	F
1	tag:	alan				
2	description	test				
3						
4	time	topValue	rightValue	bottomValue	leftValue	
5	0	0	0	0	0	
6	30000	100	0	0	0	
7	45000	0	50	60	0	
8	55000	0	0	0	0	
9	60000	0	0	0	0	
10						
11						
12						

Text | Run your own experimenter x

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4	time	topValue	rightValue	bottomValue	leftValue
5	0	0	0	0	0
6	30000	100	0	0	0
7	45000	0	50	60	0
8	55000	0	0	0	0
9	60000	0	0	0	0
10					
11					
12					

Now you need to submit your experiment.

Go to the overview page (see image below). Note the button labeled "Choose Files" - use this to select the file from your local hard drive .

Submit Pre-Programmed Experiments to Next Available Online Microscopes

No text experiments in queue. Click To Join.

Choose FilesNo file chosen

Browse to Load Text Files

Available Realtime Online Microscopes - Cl

Note: You can only run one live experiment at a time

LiveText

LiveText

LiveText

eug0 (Available)

eug1 (Available)

eug2 (Available)

If successful, it now states "Loaded 1 file(s)" and the button at the top ("Submit Pre-Programmed Experiments to Next Available Online Microscope") as well as the buttons on the individual microscopes ("Text") turn a darker blue and become available (see image below). If they do not become available, then something is wrong with your file format.

Submit Pre-Programmed Experiments to Next Available Online Microscopes

No text experiments in queue. Click To Join.

Choose FilesUser_exp...ent.csv

Loaded 1 file(s). RunTime:60 seconds.

Available Realtime Online Microscopes - Cl

Note: You can only run one live experiment at a time

LiveText

LiveText

LiveText

eug0 (Available)

eug1 (Available)

eug2 (Available)

You can now submit your experiment by pressing any of these newly-available buttons one time. After a few minutes, you will find your experiment data ready for download at the bottom of the page (see image below). You may need to refresh the page in your browser. You should then be able to "View" the corresponding movie online or "Download" it to your local drive.

All Experiment Data

Text | Run your own experimenter

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eug0 (Available)

eug1 (Available)

eug2 (Available)

You can now submit your experiment by pressing any of these newly-available buttons one time. After a few minutes, you will find your experiment data ready for download at the bottom of the page (see image below). You may need to refresh the page in your browser. You should then be able to "View" the corresponding movie online or "Download" it to your local drive.

All Experiment Data

	Submission Time	Microscope Name	Tag	Status	Experiment ID
ViewDownload	Sun Jul 03 2016 05:44:46 GMT-0700 (PDT)	eug0	live	finished	577916ce63a112626cc01af3
ViewDownload	Sun Jul 03 2016 06:43:33 GMT-0700 (PDT)	eug1	live	finished	5779168563a112626cc01af2
ViewDownload	Sun Jul 03 2016 06:42:17 GMT-0700 (PDT)	eug2	live	finished	5779163963a112626cc01af1

After downloading the file, unpack it. You will find two movies, one of which has various information overlaid on it including the yellow light indicators on the side as described on the previous page. Use this movie for the following activities throughout the course.

STAFF DEBUG INFO

Does the off-line experiment work for you?

☐ I was able to submit the experiment. I found the corresponding movie among the downloaded files, I can replay it, and I see the yellow light indicators change according to my submitted stimulus protocol. (Success! You can continue with the course.)

☐ I can watch the movie but the light stimulus sequence does not look like what I programmed (Check the csv file you generated.)

☐ I am lost - it does not work for me. (In this case you should contact us.)

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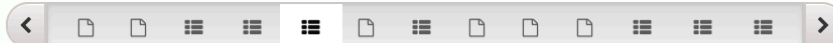
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#2: Stimulate Euglena with light > Run your own experiment! > Check question: Do you understand the light stimulus?

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Group A - no hint

Bookmark

Meaning of light indicators

(1 point possible)

What is the meaning of the white-yellow bars on the four sides of the microscope view?

- ☒ They indicate the direction the light is shining toward. ✖
- ☐ They indicate the direction the light is shining from.

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#2: Stimulate Euglena with light > Run your own experiment! > Some first basic observations

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YOUR OBSERVATIONS (1 point possible)

Did you notice any responses by the Euglena to the light when moving the joystick? Describe them here!

Your response must be between 1 and 10000 words.

Submit

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#2: Stimulate Euglena with light > Run your own experiment! > Your response to the previous open question

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Which of the following statements did you include in your last answer?

(1 point possible)

Check all that apply!

☐ I do not see any *Euglena* cells at all.

☐ I see the *Euglena* swim around, but I do not see any changes in their behavior when I change the light stimulus.

- *Euglena* spin around themselves but they do not move forward much.

■ If I look very carefully, I can see that *Euglena* roll around their own long axis while they swim forward.

- The response to light is not instantaneous, instead it often takes 5-10 seconds to see changes in swimming direction.

- ☐ Euglena swim away from the light.

- ☐ Euglena swim towards the light.

☐ Other / additional observations not mentioned in this list.

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#2: Stimulate Euglena with light > Run your own experiment! > Reproducibility of results

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REPRODUCIBILITY OF RESULTS

A very important part of science is making sure that observations are reproducible and generalizable.

So far you have seen how Euglena react (or not) to light stimuli during one experiment. But do they always act this way? Do different cultures of Euglena behave differently?

We have multiple online microscopes prepared for you; some have different magnifications. You can access each of these microscopes directly by pressing "Live" (see image below).

Repeat your exploration on at least two other microscopes - having three independent observations is usually a good start to assess what might be generalizable as well as what happens sometimes but not always.

Interactive Online Biology

Updated: Mon Jul 04 2016 23:44:36 GMT-0700 (PDT)

Live and Real Available Online Microscopes

No live experiments in queue at any time. Click to join.

Queue the Programmed Experiment to Live Available Online Microscopes

No test experiments in queue. Click to join.

Choose Flip: No live chosen

Buttons to Load Test Flip

Available Realtime Online Microscopes - Choose One

Note: This user only can view live experiment at a time

Live Test

Live Test

Live Test

Single (Standard) Time Left: seconds MicroscopyImage

Single (Standard) Time Left: seconds MicroscopyImage

Single (Standard) Time Left: seconds MicroscopyImage

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YOUR GENERALIZED OBSERVATION FROM THREE DIFFERENT EXPERIMENTS

(1 point possible)

Did you notice anything new in these other two experiments? What does generalize? What is unique?

Your response must be between 1 and 10000 words.

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#2: Stimulate Euglena with light

Run your own experiment! Activity

#3 Qualitative post-experiment data analysis

#4: Euglena structure and control feedback for robust phototaxis

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#2: Stimulate Euglena with light > Run your own experiment! > Trouble shooting if needed

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TROUBLESHOOTING EUGLENA LIGHT RESPONSE

At this point you should have observed some light response from Euglena in at least one microscope, and there should have been individual Euglena that move away from light.

In case you have not, here is what you should do (otherwise you can go on to the next page):

- Try holding the light joystick for longer or shorter periods of time. Sometimes the responses are immediate and obvious - the swimming paths are very straight away from the light - but sometimes they are not.
- Try different intensities. Sometimes you need the full light intensity to make the cells move, but sometimes you need to use a middle intensity range since for full intensity they can spin without much forward movement.
- Be patient. Euglena have a circadian rhythm, just as humans do: cells respond differently at different times of the day. Furthermore, we have multiple online microscopes, so try them all.

This is biology. Understanding behavioral variability is also an ongoing research question. Play around.

If you still cannot get it to work - contact us (see email at the beginning of the course).

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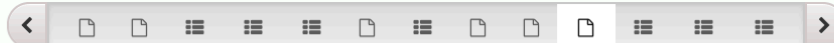
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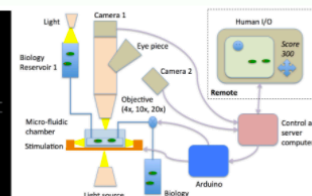
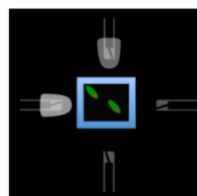
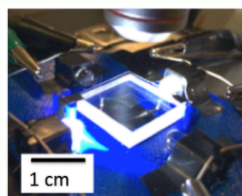
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HOW THE INTERACTIVE ONLINE MICROSCOPE WORKS:

The microscopes are housed in the Riedel-Kruse lab. A microfluidic chamber is placed under the microscope. Inside this chamber the *Euglena* are situated in water. The chamber is square with the dimensions 5 mm x 5 mm x 0.1 mm (W x L x H) and has an inlet and an outlet through which fresh *Euglena* can be flushed into the chamber from time to time. *Euglena* are automatically cultured in an attached chamber, and the whole culture lives stably for multiple weeks without the need for human intervention. On each of the four sides of the chamber there is an LED that you can control with your joystick. [In this online microscope you therefore see a quasi 2D plane from above with *Euglena* inside and one LED on each of the four sides.](#)



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#2: Stimulate Euglena with light > Run your own experiment! > How does Euglena change swimming direction due to light?

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Which of the following statements applies?
(1 point possible)
Check all the answers that are correct.

☐ Euglena are elongated cells that move in response to light.

☐ The online microscope allows you to project light from four directions onto these cells via four LEDs.

☐ All Euglena cells are perfectly identical in their looks and behavior.

☐ As a user you can turn on exactly one of the four LEDs at the time.

?

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Euglena Behavior

Eugenia Behavior
(1 point possible)

If the light is very bright then *Euglena* swims away from it. Why do you think this behavior is helpful for *Euglena*?

- ☐ This is not true. Euglena always swim towards to light no matter how bright it is.
- ☐ Euglena always stays in the dark because predators cannot find it there.
- ☐ If the light is too bright then Euglena might get UV damage.
- ☐ Euglena will typically find other cells to eat in the dark that hide there.

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EUGLENA PHOTOTAXIS - AND RELATION TO ITS STRUCTURE

Let's look again at *Euglena* (images below). *Euglena* has an elongated green cell body that contains green chloroplasts, which perform photosynthesis and harvest energy for light. *Euglena* also has a long slender flagellum that beats and propels the cell through the fluid as well as a red eye spot that detects where the light is coming from. The tight coordination between eye spot and flagellum allows *Euglena* to swim towards or away from the light. This behavior is called "phototaxis." In the online microscope you have primarily witnessed negative phototaxis.

Such "taxes" to external stimuli are very common to single-celled organisms. Besides responding to light, cells can respond to many other stimuli such as chemicals, gravitation, temperature, magnetic fields, or electric fields ("chemotaxis," "thermotaxis," "gravitaxis," "magnetotaxis," or "galvano-taxis," respectively). Each taxis can be positive or negative, e.g., the cell can swim towards or away from light which are called "positive phototaxis" and "negative phototaxis," respectively. If it is very dark, then *Euglena* will swim to the light since it needs light to do photosynthesis, but if the light is extremely strong, then *Euglena* will move away as it may get UV damage (like a human getting a sunburn).

In this course we want to understand how such small and simple organisms are able to perform such a "taxi". We will do this using the example of *Euglena*'s "negative phototaxis," i.e., *Euglena* swimming away from strong light. If we wanted you to experience positive phototaxis on this online microscope very robustly, we would have to make the background light so dim that it would be hard for you to see these cells. Hence we focus in this course on negative phototaxis - but all you



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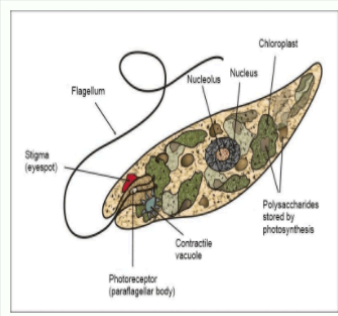


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Let's look again at Euglena (images below). Euglena has an elongated green cell body that contains green chloroplasts, which perform photosynthesis and harvest energy for light. Euglena also has a long slender flagellum that beats and propels the cell through the fluid as well as a red eye spot that detects where the light is coming from. The tight coordination between eye spot and flagellum allows Euglena to swim towards or away from the light. This behavior is called "phototaxis." In the online microscope you have primarily witnessed negative phototaxis.

Such "taxes" to external stimuli are very common to single-celled organisms. Besides responding to light, cells can respond to many other stimuli such as chemicals, gravitation, temperature, magnetic fields, or electric fields ("chemotaxis," "thermotaxis," "gravitaxis," "magnetotaxis," or "galvano-taxis," respectively). Each taxis can be positive or negative, e.g., the cell can swim towards or away from light which are called "positive phototaxis" and "negative phototaxis," respectively. If it is very dark, then Euglena will swim to the light since it needs light to do photosynthesis, but if the light is extremely strong, then Euglena will move away as it may get UV damage (like a human getting a sunburn).

In this course we want to understand how such small and simple organisms are able to perform such a "taxis". We will do this using the example of Euglena's "negative phototaxis," i.e., Euglena swimming away from strong light. If we wanted you to experience positive phototaxis on this online microscope very robustly, we would have to make the background light so dim that it would be hard for you to see these cells. Hence we focus in this course on negative phototaxis - but all you learn applies very generally to positive phototaxis and even to all sorts of other taxes mentioned above.



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SECTION SUMMARY

Now you have seen qualitatively what is going on: Euglena cells generally swim around rather randomly, but when the light turns on many start responding. One of the prevalent responses is movement away from light; another response type, especially at very high intensities, is that Euglena might spin around at their current position. Next we will look at some qualitative data analysis tools to study these behaviors a bit more closely.

Congratulations - You finished section #2!

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How much time did you spend on section #2?
(1 point possible)
Time in minutes:

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Now go to section #3 (selection on the left side of the screen).

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SECTION OVERVIEW

In this section we will show you how you can view, download, and analyze your own data. You will learn how to make qualitative observations and simple measurements to better understand how Euglena accomplishes phototaxis.

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VIEWING AND DOWNLOADING EXPERIMENTAL DATA

(Note: In case you had trouble earlier you may already have seen this page - in which case you can jump ahead.)

Besides watching the experiments live and in real time, there are two more ways for you to look at your experimental data after the experiment has finished: (1) **The online movie viewer** that allows you to replay your previous experiments in the browser; (2) **a set of downloadable files** that includes this movie and additionally various quantitative data (such as speed and position of the majority of Euglena, direction of light stimulus, etc.) for your previous experiments.

Go to the overview page of your online microscope <http://euglena.stanford.edu/account/> (we recommend you just keep that tab open). Scroll down to find the list of all your previously executed experiments (it may take 2-3 minutes after you finished an experiment before it shows up here, though typically it is much faster - you may potentially need to refresh your browser page):

All Experiment Data

	Submission Time	Microscope Name	Tag	Status	Experiment ID
View Download	Sun Jul 03 2016 06:44:46 GMT-0700 (PDT)	eug0	live	finished	577916cae63a112626cc01af3
View Download	Sun Jul 03 2016 06:43:33 GMT-0700 (PDT)	eug1	live	finished	5779168563a112626cc01af2
View Download	Sun Jul 03 2016 06:42:17 GMT-0700 (PDT)	eug2	live	finished	5779163963a112626cc01af1

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Each row is a different experiment. Select **"View"** and a movie viewer will open in a new tab. Select **"Download"** and a complete data set will be downloaded onto your hard drive; unpack that file and you will find two mp4 files, one is raw and the other has various information overlaid.

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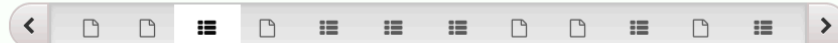
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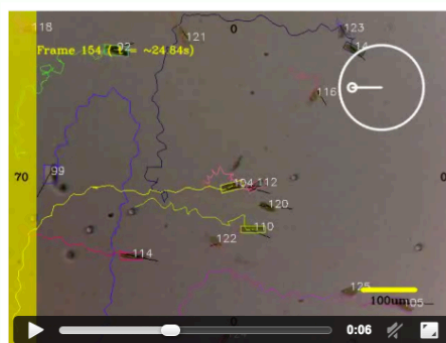
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EXPERIMENT MOVIE VIEWER

Now you are in the experiment movie viewer mode, which should look like the following:



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Use the play button and the slider to explore.

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Does your own experiment viewer work for you / can you look through your previous experiment?

(1 point possible)

☒ Yes - I can play it back and forth and I see multiple Euglena moving and some additional overalays.

☐ No - I don't see any movie. I should check instructions again and potentially seek help.

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Features in your movie

Features in your
(1 point possible)

Which of the following features do you notice in your movie? Check all that apply!

- In the upper left there is a frame number and also real time.

■ On each of the four sides there is number showing the amount of light coming from that direction.

■ The joystick in the upper right corner shows the light stimulus - and there is a correlation between the light indicators on the four sides and this joystick (e.g., when the joystick points to

EXPERIMENT MOVIE VIEWER x

You

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Features in your movie
(1 point possible)
Which of the following features do you notice in your movie? Check all that apply!

☐ In the upper left there is a frame number and also real time.

☐ On each of the four sides there is number showing the amount of light coming from that direction.

☐ The joystick in the upper right corner shows the light stimulus - and there is a correlation between the light indicators on the four sides and this joystick (e.g., when the joystick points to the left but does not fully reach the white circle, the number on the left is 70, while the other three numbers are 0, indicating 70% and 0% light, respectively).

☐ The swimming traces of Euglena are automatically tracked, and the trace is drawn onto the movie.

☐ Euglena cells are labeled with white numbers.

☐ Every Euglena is tracked perfectly all the time.

☐ There is a scale bar on the lower right.

?

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In case you had troubles answering the last question - here some explanation regarding the experiment movie viewer:

(1) Euglena are automatically tracked; each track is colored differently, and each Euglena has a unique number.

(2) Time and frame information are in the upper left corner.

(3) Animation of the joystick motion that generated that experiment, in the upper right corner.

(4) Light values of the four LEDs are shown on all four sides, ranging from 0 to 100% ("off" to "on max").

(5) The scale bar (100 micrometers) is in the bottom right corner.

(6) Euglena are not perfectly tracked! Sometimes the algorithm loses a cell (especially when two cells swim over each other). In case the tracking algorithm loses a cell for a few frames and then finds it again, then both traces have their own, different numbers ("Track ID").

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FIRST OBSERVATIONS FROM WATCHING THE VIDEO (1 point possible)

When looking through the video, what do you observe?

Your response must be between 1 and 10000 words.

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You have used 0 of 1 submission

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Statements included in last answer

(1 point possible)

Which of the following statements did you include in your last answer? Check all that apply!

☐ (Some) Euglena change their behavior in some way when the light comes on.

☐ (Some) Euglena make a very clear turn when the light comes on.

☐ (Some) Euglena do not seem to respond to the light.

☐ There is variability in Euglena swimming behavior.

☐ Euglena swim along a meandering path instead of perfectly straight.

☐ Euglena swim away from the light.

☐ Other / additional ones not mentioned in this list.

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"Guesstimate" of Euglena speed

(1 point possible)

You can also use the video to estimate how fast *Euglena* moves forward (what its speed is).

Scroll through your movie and pick a Euglena cell that looks representative in its behavior. Using the scale bar and timer on the movie, estimate its speed based on how much it traveled over a few frames. (Speed is defined as distance traveled divided by the amount of time it took.)

What is the speed you measured, in micrometers/sec?

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Euglena that change directions due to light

(1 point possible)

Go back to your movie and find a Euglena that clearly changes direction when the light comes on. Write down the frame number and Track ID number of that Euglena.

Frame number:

Track ID number:

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Example of Euglena respondin x

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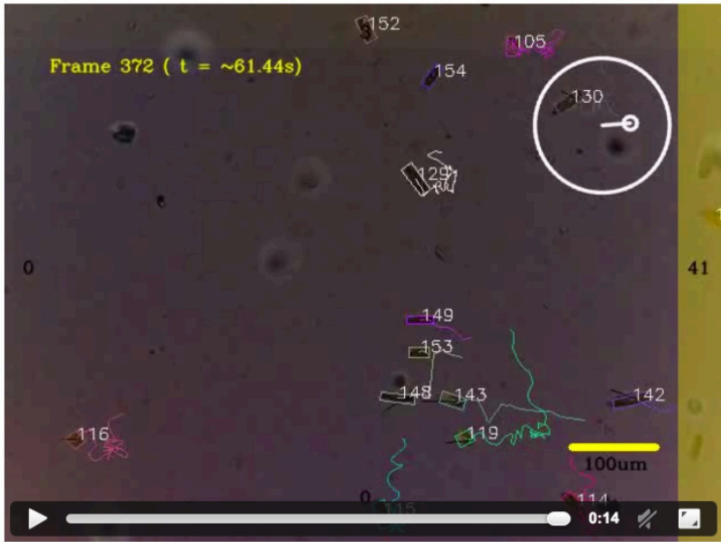
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EXAMPLE OF EUGLENA RESPONDING TO LIGHT

See screenshot examples below (Frame #372 and Track ID #119).

Note how the Euglena turns and how the Euglena paths, even before the light changes, are never perfectly straight. They instead seem to meander or wobble back and forth.





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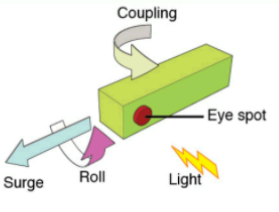
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EUGLENA CONSTANTLY ROLLS AROUND ITS OWN AXIS

This 'meandering' or 'wobbling' swimming path of Euglena is due to it rolling around its long axis. Can you guess how this works?





(Image copyrights: see end of course).

ENTER YOUR HYPOTHESIS: (1 point possible)

Why do you think it is helpful to Euglena to roll around its own axis? Why do you think it is helpful to wobble sideways rather than just to swim straight?

Your response must be between 1 and 10000 words.

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#3 Qualitative post-experiment data analysis > Qualitatively analyze and interpret your data! > Rolling question

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Estimate how fast *Euglena* rolls around its axis

(1 point possible)

Go back to your movie and estimate how quickly Euglena rolls around its axis based on its periodic sideways motion. Use units of 1 roll/sec.

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EXAMPLE MEASURING THE 'WOBBLING FREQUENCY' OF EUGLENA AROUND ITS OWN AXIS

The question about the frequency of the rolling motion can also be answered by looking at the wobbling frequency, i.e. how often the cell wobbles back and forth within a certain amount of time. In the example below Euglena #39 has completed two oscillations over a time of about 4 seconds - hence the 'wobbling' frequency is $2 \text{ rolls}/4\text{sec} = 0.5 \text{ Hz}$.



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SECTION SUMMARY

You just did some basic, mostly qualitative analysis of your experimental data. You have seen that this experimental data (here in the form of a video with all of the cellular motion tracked) contains a lot of interesting information and allows you to study cellular behavior in detail. In particular you are able to compare individual Euglena with each other and also make simple measurements like the Euglena speed.

Next we will ask how a single cell really accomplishes such complex tasks, and how all of that works at a sub-cellular level.

Congratulations - You finished section #3!

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How much time did you spend on section #3?
(1 point possible)
Time in minutes:

?

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Now go to section #4 (selection on the left side of the screen).

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SECTION OVERVIEW

Now we will underpin theoretically what we have seen in the experiments. In particular, you should have noticed that Euglena have the tendency to move away from the light, and when you change the direction of light very suddenly, then Euglena starts to adapt its swimming direction (with a certain response time) to this new stimulus.

We will now discuss how the flagellum and the eyespot work together, ultimately leading to robust phototaxis, i.e., moving away from the light or toward the light.

We will also explore some interactive model simulations to gain a better and more quantitative intuition of how this phototaxis control mechanism works.

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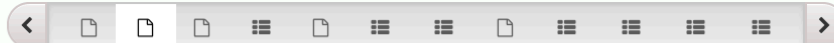
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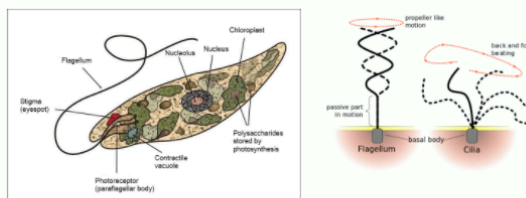
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THE FLAGELLUM AND ITS BEAT PATTERNS

The flagellum on the front of the Euglena can perform many different beat patterns. Depending on this pattern the cell can move forward, turn sideways, and/or roll around its long axis. This flagellum beats 20-40 times per second (20-40 Hz). Unfortunately, it is not possible to directly see the flagellum with our online microscope since it is very thin and beats quickly. However, better light microscopes and high speed cameras can capture these beat patterns nicely.



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Note that the underlying structure of the flagellum - the so-called axoneme - is a very common structure in many organisms. A human sperm tail or the cilia of the human lung epithelium has the same internal make-up as the Euglena flagellum. For historic reasons, shorter flagella are often called cilia.

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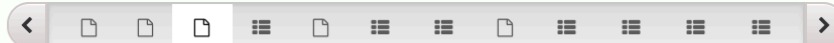
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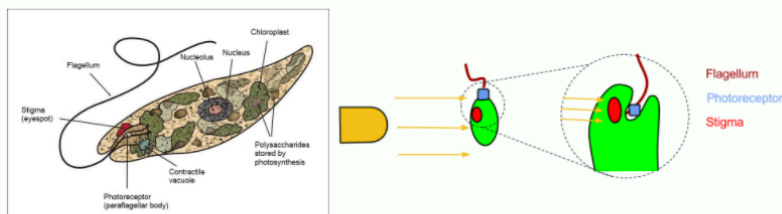
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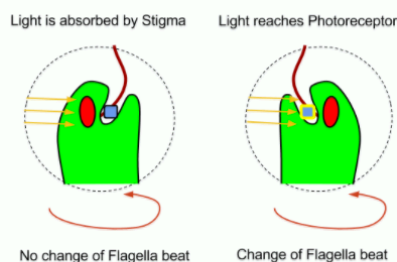
EYE SPOT, PHOTORECEPTOR, COUPLING TO FLAGELLUM, AND REORIENTATION FEEDBACK MECHANISM

There is a red "eyespot apparatus" (also termed stigma) located at the front of the *Euglena* cell body next to the base of the flagellum. It is thought that this visible eyespot actually acts as a shade/light blocker for a much smaller photoreceptor sitting next to the stigma, right at the base of the flagellum.



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Depending on whether light hits the photoreceptor directly or whether the stigma is in between to block the light, the photoreceptor does or does not get activated. This then leads to a change in the beating pattern of the flagellum (or not).

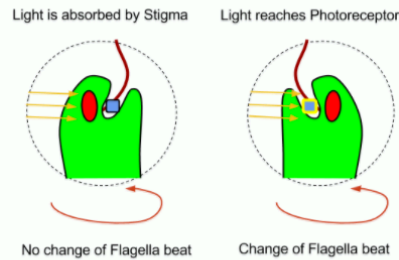


When the Euglena cell rotates around its axis while swimming forward, a light source coming from the side would therefore periodically activate the photoreceptor, which would then periodically change the flagellar beating pattern. This would ultimately lead to a feedback loop that turns the Euglena such that it swims parallel to the light. Once swimming is parallel to the light direction, the stigma does not shade the photoreceptor any longer and the photoreceptor receives a constant light stimulus. The beating pattern of the flagellum is no longer altered anymore, so the Euglena swims straight.

(Actually, the cell still slightly wobbles, even when swimming parallel to the light. The receptor receives smaller light stimuli periodically, which enable the cell to self-correct and keep its path.)

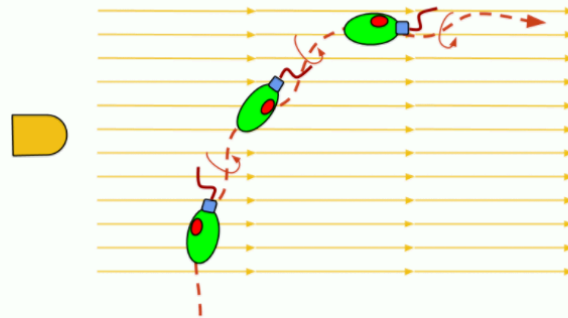
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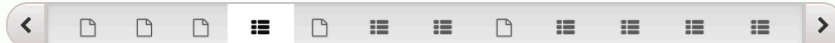
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Test question

Test question
(1 point possible)

What part (organelle) of Euglena makes it move through the fluid?

- The chloroplast.

- The flagellum.

- The eye-spot.

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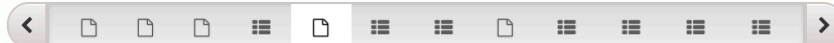
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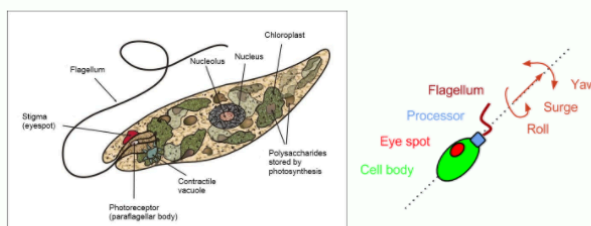
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THE DYNAMIC ROLL-AND-TUMBLE MODEL FOR EUGLENA

We already noticed that Euglena has just one eye which is not even a real eye, just a spot to recognize whether there is more or less light coming from the direction it is currently pointing toward. Just having one eye itself limits the possibility to see where the (potentially damaging) light is coming from. As we saw previously, the Euglena constantly rolls and tumbles (wobbles) around its own swimming direction. This is how it can continuously scan in all the directions to detect where the light is coming from.

Projecting this into a 2D scenario, this means that *Euglena* periodically scans all directions perpendicular to its swimming direction. If you just consider its motion in the plane - then it basically looks periodically to the left and to the right.

Questions for self-reflection: How does the tumbling/wobbling/Yaw motion come about? Does this happen all the time? What does it allow the *Euglena* to do that would be difficult to do otherwise?



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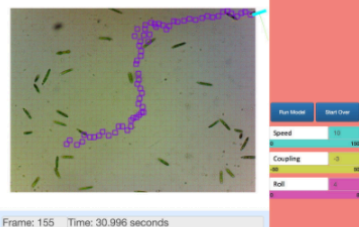
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INTERACTIVE MODEL EXPLORATION

In order to give you some intuition of how such a model behaves , we have created an interactive simulation for you to play with. Go to the modeling website <http://euglena.stanford.edu:8080/> (left image). **NOTE: THIS SITE IS DIFFERENT FROM THE ONLINE MICROSCOPE. You should be able to use the same username and password as before, but in case it gives you an error, generate a new account using the same user name and password.** Now login and you will see the modeling interface (right image):





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The behavior of this model Euglena is determined by the three variables shown on the right: forward speed, coupling strength between light and sideways motion, and roll frequency. Try different values, hit RUN, and explore what their effect is on the swimming path.

Note that there is a Euglena movie in the back, and for one of these real Euglena a path was actually traced in purple. Furthermore, there is a light stimulus sequence influencing your model Euglena which is the same as the one that was used during the real experiment shown in the background. Can you find a reasonable quantitative parameter set that make this model Euglena swim along the traced purple path?

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How successful was your modeling?
(1 point possible)

☐ I was able to achieve a reasonable fit between model and trace from the real Euglena.

☐ Although the modeling site works - I could not get any reasonable fit.

☐ I have big problems with the website - there are glitches or it does not even load at all.

?

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Values of your fit parameters
(3 points possible)

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Interactive model exploration

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☐ I was able to achieve a reasonable fit between model and trace from the real Euglena.

☐ Although the modeling site works - I could not get any reasonable fit.

☐ I have big problems with the website - there are glitches or it does not even load at all.

?

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Values of your fit parameters
(3 points possible)
Now enter the values of the three parameters that gave you your best fit.

Speed [micrometers / sec] (variable 1):

?

Coupling [arbitrary unit] (variable 2):

?

Rolling frequency around long axis [1 / sec] (variable 3):

?

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Positive vs. negative phototaxis

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POSITIVE VS. NEGATIVE PHOTOTAXIS

The model parameters you eventually found led to a Euglena that performed negative phototaxis (it swam away from the light).

Can you find parameter configurations that make the Euglena model swim towards the light? Go back to the modeling website <http://euglena.stanford.edu:8080/account/> and try.

STAFF DEBUG INFO

Key change to make
(1 point possible)

What is key change you need to make to the parameters to obtain a Euglena model with positive photo-taxis?

☐ It works for certain combinations of Speed and Roll, and the higher you make the Speed, then the higher you must make the Roll.

☐ The Roll parameter needs to be 1.

☐ The Coupling parameter needs to be positive.

☐ It is impossible to make the model go towards the light.

?

SUBMIT

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Best fit model
(1 point possible)

Does your 'best fit model' wobble around its axis?

☐ No - never.

☐ Yes - always.

☐ Yes - but only when the light is on.

☐ Yes - but only when the light is off.

?

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Repeat experiments with a fres

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#4: Euglena structure and control feedback for robust phototaxis > Formulate explanations and develop models! > Go back to the online lab - anything new you see?

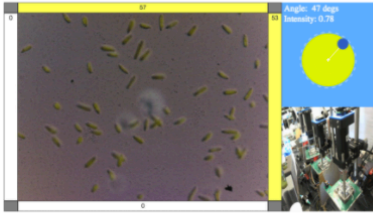
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REPEAT EXPERIMENTS WITH A FRESH MIND

Now go back to the online microscope (<http://euglena.stanford.edu/account/>) and stimulate the Euglena again with the joystick. Is there anything new that you realize now about Euglena after doing the modeling exercise?

eug0 Time Remaining: ~30 seconds.



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WHAT ARE BEHAVIORS OF REAL EUGLENA YOU NOTICE THAT THE MODEL DOES NOT CAPTURE?

(1 point possible)

Your response must be between 1 and 10000 words.

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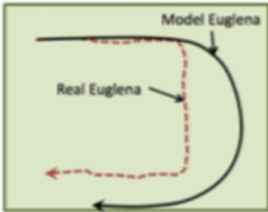
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MODELING QUESTION 1

In the following sections we have a few simple questions related to the model you just explored. Always feel free to go back to the virtual model and explore more if needed.

For these questions, you will see a sketch of the real trace (red dashes) under the influence of three sequential LED inputs (i.e., light from the left, then top, then right). The black trace is the model Euglena.



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Three model parameters
(1 point possible)
Which of the three model parameters needs tuning to achieve a better agreement between model and real data? (see image above)

☐ Speed

☐ Roll

☐ Coupling

?

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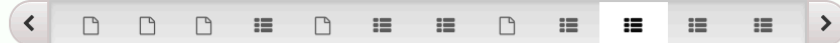
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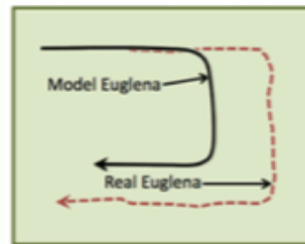
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MODELING QUESTION 2

Which of the three model parameters needs tuning to achieve a better agreement between the model and the real data?



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Three model parameters

(1 point possible)

Which of the three model parameters needs tuning to achieve a better agreement between model and real data?

- Speed

☐ Roll

- Coupling

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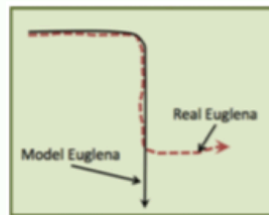
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MODELING QUESTION 3

Which of the three model parameters needs tuning to achieve a better agreement between the model and the real data? Note also that this time the swimming path of the *Euglena* is slightly different (the sequence of LEDs was different).



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Three model parameters
(1 point possible)

Which of the three model parameters needs tuning to achieve a better agreement between the model and the real data?

- Speed

☐ Roll

- Coupling

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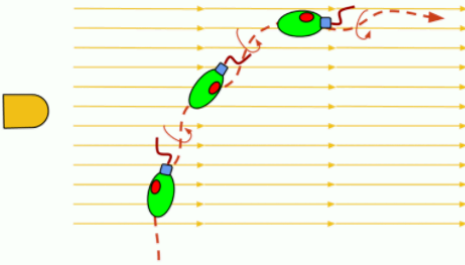
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SECTION SUMMARY

As you saw, the model was able to explain a robust light avoidance response as the cell periodically turned its eye spot towards and away from the light by rolling around its axis. The eye spot ("stigma") sits close to the base of the flagellum. When the light intensity that reaches this eye spot changes, the flagellum changes its beating behavior. This suggests a feedback mechanism where reorientation of eye spot relative to the light (caused by the flagellar beat) leads to changes in how much light hits the eye spot. This is then conveyed to again change the beating pattern of the flagellum. Note, there is a slight, self-correcting tumbling motion around the cell's long axis that also allows it to peek forward and backward a little bit.

A diagram of a green Euglena cell with a red eye spot (stigma) and a blue flagellum. The cell is shown in a tumbling motion, indicated by red dashed lines and arrows. Horizontal yellow arrows represent light rays coming from the left. The cell's orientation changes as it moves through the light field.

(Image copy rights: see end of course).

Likely, there are also many more subtle things going on. There is a corresponding famous quote: "All models are wrong - but some are useful."

Congratulations - You finished section #4!

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How much time did you spend on section #4?
(1 point possible)
Time in minutes:

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Now go to section #5 (selection on the left side of the screen).

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Optimal microscope for statist x

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Optimal microscope for statistical data analysis

(1 point possible)

If you want to do statistical anaylsis on many Euglena cells to study their behavior (such as measuring their speed), which kind of microscope do you think is better?

High magnfication (like microscope eug0 and eug1).

Low magnfication (like microscope eug3 and eug15) .

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GENERATE AND DOWNLOAD A SUITABLE DATA SET FOR QUANTITATIVE ANALYSIS

For the following activities it would be good for you to have an experimental data set that has roughly the following features:

(i) You had light on from at least one of the primary directions (only a single LED was on) for at least 10 seconds and during that time you very clearly saw directional motion for a significant portion of the Euglena cells.

(ii) You had no light on at all for at least 10 seconds (ideally at the start of the experiment) - certainly long enough that visually you felt there is no directed motion anymore.

(iii) You used a microscope showing very large number of cells, i.e., having used a microscope with low(!) magnification, e.g., microscopes eug3 or eug15.

Download your dataset (go to <http://euglena.stanford.edu/account/> and at the bottom of the page use the "Download" button for the experiments of interest). **In case you don't have a suitable file to work with yet, go back to the online microscope and generate one.** This is important - otherwise your analysis results may not be very obvious. In case you find it difficult to generate a data set such as that described above: start with 15 seconds of no light, and then try the different joystick directions for approximately 5 to 10 seconds - potentially going to intermediate intensity - and when you see directed motion, keep conditions constant until the experiment is over. You can also try multiple times, or you may also choose a different microscope where the Euglena behave slightly differently. In our experience one usually can achieve suitable data on the first or second try.

Remember, you can always watch a video of an experiment to check what the light stimuli and Euglena behavior were like.

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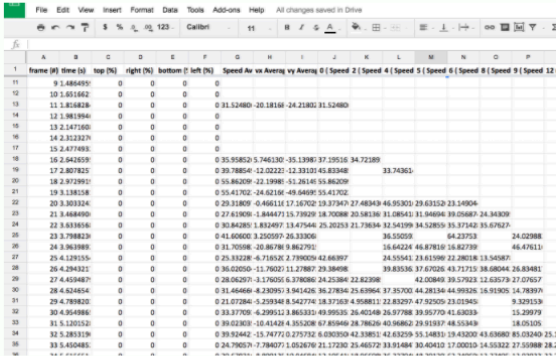
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LOADING DATA INTO GOOGLE SHEETS

For the following analysis we will now use Google Sheets: <https://www.google.com/sheets/about/>. We picked Google Sheets because it is free to use and advantageous to know. Although there are many other suitable programs in principle, including Microsoft Excel, we strongly recommend you stick to Google Sheets, otherwise it might be harder for you to follow our examples and instructions.

Unpack the downloaded file. (If you have trouble unpacking the file , go to <http://www.7-zip.org/>. If you still have trouble, contact us.)

Among the files inside the folder that will appear, open the file named 02_Track_Speed_With_Average_Velocities_Series.xlsx in Google Sheets. You should see the following (with different numbers, of course):



(Image copyrights: see end of course).

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Ease of accessing data
(1 point possible)

How easy was it for you to download the data and then open it up in Google Sheets?

☐ It was easy.

☐ I struggled a bit but eventually figured it out.

☐ I still don't know how to do it even though I tried to follow all the provided explanations.

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A BRIEF EXPLANATION OF THE SPREADSHEET

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Ease of accessing data
(1 point possible)
How easy was it for you to download the data and then open it up in Google Sheets?

☐ It was easy.

☐ I struggled a bit but eventually figured it out.

☐ I still don't know how to do it even though I tried to follow all the provided explanations.

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A BRIEF EXPLANATION OF THE SPREADSHEET

The top row is the header that contains identifiers for each column. Each of the other rows contains the information for every single frame in your movie. The columns A and B are the frame number and the time stamp in seconds, respectively. The next four columns (C-F) provide intensity information for the four LEDs (between 0 and 100%).

Each of the columns from J on are dedicated to an individual Euglena - the header row refers to the number of the specific Euglena, as shown in the experiment movie. Each entry in a column contains the speed for that Euglena at that point in time. Many cells in the sheet are left blank because each Euglena is present under the microscope for only some time during the experiment, and even when a Euglena is present, it might not be properly detected by the algorithm all the time.

Finally, column G is the average speed of all Euglena at that particular frame, and columns H and I are the average velocity components of all Euglena at that frame.

To make viewing easier, you can also select the cell "I1", and then choose from the menu "View" - "Freeze" - "Up to current row" and "Up to current column".

Now let's start with the initial analysis and visualization of your data.

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DATA ANALYSIS - VARIABILITY OVER TIME AND BETWEEN EUGLENA

Now let's have a look at the data. We provide an example below , but you should look at your own data in parallel.

First, let's focus on the data column for a single Euglena - for example column J , Euglena #0 (highlighted in yellow in the example).

Is the speed always the same? No, it is not. Where does this variability come from?

There are two sources: (1) The Euglena actually does not keep a perfectly constant speed and (2) there are measurement uncertainties.

Second, let's focus on a single time point for all the Euglena - for example row 30, frame 28 (highlighted in green in the example).

Is that speed always the same?

Clearly not. Apart from the variation of the single Euglena already discussed, it also becomes clear that each Euglena is an individual and that these different cells differ from each other in their properties.

(This raises of course the question of how much variability stems from measurement error, single Euglena variation, and variation between Euglena. This can get complicated, so we will not go deeper into these issues during this course.)

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IMAGE MODAL XBLOCK

Fullscreen

36.2783482241012

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	frame (#)	time (s)	top (%)	right (%)	bottom (%)	left (%)	Speed Av vx	Average vy	Average 0	Speed 2	Speed 4	Speed 5	Speed 6	Speed 8	Speed 9	Speed 12	Sp
15	13	2.147160	0	0	0	0											
16	14	2.312327	0	0	0	0											
17	15	2.477493	0	0	0	0											
18	16	2.642659	0	0	0	0	0.35.95852	5.746130	-35.13987	37.19516	34.72189						
19	17	2.807825	0	0	0	0	0.39.78854	-12.0222	-12.33101	45.83348							
20	18	2.972991	0	0	0	0	0.55.86209	-22.19985	-51.26145	55.86209							
21	19	3.138158	0	0	0	0	0.55.41702	-24.62166	-49.64695	55.41702							
22	20	3.303324	0	0	0	0	0.29.31809	-0.466116	17.16702	19.37347	27.48343	46.95301	29.63152	23.14904			
23	21	3.468490	0	0	0	0	0.27.61909	-1.844471	15.73929	18.70088	20.58136	31.08541	31.94694	39.05687	24.34309		
24	22	3.633656	0	0	0	0	0.30.84285	1.832497	13.47544	25.20253	21.73634	32.54199	34.52855	35.37142	35.67627		
25	23	3.798823	0	0	0	0	0.41.60600	3.250597	26.33306								
26	24	3.963989	0	0	0	0	0.31.70598	-20.86786	9.862791								
27	25	4.129155	0	0	0	0	0.25.33228	-6.71652	2.739005	42.66397							
28	26	4.294321	0	0	0	0	0.36.02050	-11.76027	11.27887	29.38498							
29	27	4.459487	0	0	0	0	0.28.06297	-3.176051	6.378086	24.25384	22.82398						
30	28	4.624654	0	0	0	0	0.31.46466	-8.230951	3.941426	36.27834	25.63964	37.35700	44.28134	44.99326	16.91905	14.78397	
31	29	4.789820	0	0	0	0	0.21.07284	-5.259348	8.542774	18.37163	4.958811	22.83297	47.92505	23.01945			
32	30	4.954986	0	0	0	0	0.33.37709	-6.299512	3.865331	49.99535	26.40148	26.97788	39.95770	41.63033			
33	31	5.120152	0	0	0	0	0.39.02303	-10.41428	4.355208	67.85946	28.78626	40.96862	29.91937	48.55343			
34	32	5.285319	0	0	0	0	0.39.92442	-15.74772	0.275732	6.030350	42.33851	42.63259	55.14831	19.43200	43.63680	85.03240	25.144
35	33	5.450486	0	0	0	0	0.74.79073	-7.78467	1.052676	91.12730	35.46537	33.91484	30.48410	17.00010	14.55537	77.55688	78.754

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Maximal, minimal, average value (1 point possible)

To get a feel for this variability, pick an area of about 10 Euglena and 10 frames in your spreadsheet and look for the maximum, minimum, and approximate average value.

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Data analysis | Analyze your data

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Maximal, minimal, average value
(1 point possible)
To get a feel for this variability, pick an area of about 10 Euglena and 10 frames in your spreadsheet and look for the maximum, minimum, and approximate average value.

What is the smallest speed you find? (all questions in units of micrometers / sec).

?

What is the maximum speed you find?

?

What is the approximate average speed you find? (just eyeball it - no need to calculate)

?

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Euglena speed
(1 point possible)
Do all Euglena have the exact same speed?

Yes

No

?

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GRAPHICAL REPRESENTATION OF DATA - SPEED AND LIGHT STIMULUS OVER TIME

Now let's plot the average speed over time together with the information about the light direction and intensity so that we can see what *Euglena* are actually doing over time, particularly in response to light.

We are providing you with three different sets of instructions: Expert, Intermediate, and a detailed walk-through for Beginners. Pick the level you feel most comfortable with. Some trial and error before going through the detailed walk-through often deepens the learning.

Instructions for Experts:

Plot the intensity data of the four LEDs and the average speed data in a single plot over time. Properly label the two axes and give a descriptive title.

Instructions for Intermediates:

1. Go back to the same data set you have been working with in Google Sheets.
2. We will now make a graph. Since we want to plot the LED values as well as the average speed over time, select columns B, C, D, E, F, and G all at once. (You can select individual columns by holding the "Command" key while selecting with the mouse cursor).
3. Go to "Insert Chart", select "Chart types", and select "Area" (the first option given). Check the following boxes if they are not yet checked automatically: "Use row 1 as header" and "Use column B as labels".
4. Label the x-axis as "Time [sec]"; label the y axis as "Speed [micro-meter / sec] / light intensity [a.u.]". Give the chart the title "Speed and directional light intensity over time".
5. Finally, press "Insert" and you are done.

Instructions for Beginners (detailed walk-through):

Go to the next page, and we will provide you with a detailed graphical solution.

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#5: Quantitative data analysis > Analyze your data quantitatively and test hypotheses! > Detailed data plotting solution

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DETAILED INSTRUCTIONS FOR GRAPHING THE DATA

You can skip this page if you were successful making the graph on the last page. Otherwise, go back to the data set you have been working with on Google Sheets.

We are going to make a graph. As we want to plot the LED values as well as the average speed over time, you will need to select columns B, C, D, E, F, and G all at once. (You can select individual columns by holding the "Command" key while selecting with the mouse cursor).

File Edit View Insert Format Data Tools Add-ons Help All changes saved in Drive														
fx time (s)														
	A	B	C	D	E	F	G	H	I	J	K	L		
1	frame (s)	time (s)	top (%)	right (%)	bottom (%)	left (%)	Speed Average	Avx Average	vy Average	O (Speed 2)	Speed 4	Speed 8		
2	0	0	0	0	0	0	0	0	0	0	0	0		
3		1.0347856	0	0	0	0	0	0	0	0	0	0		
4		2.295712	0	0	0	0	0	0	0	0	0	0		
5		3.0443568	0	0	0	0	0	0	0	0	0	0		
6		4.0591424	0	0	0	0	0	0	0	0	0	0		
7		5.0739280	0	0	0	0	0	0	0	0	0	0		
8		6.0887136	0	0	0	0	0.3826455	80.781233	-78.92357	112.93596				
9		7.1034992	0	0	0	0	0.1093952	3.607110	-19.8910	20.16436				
10		8.1182848	0	0	0	0	0.2967807	9.883482	-49.34527	50.32533				
11		9.1330704	0	0	0	0	0.7325514	32.77059	-44.39442	55.14329				
12		10.1478561	0	0	0	0	0.3189188	13.34530	-7.334457	107.7979	41.20689	31.1344		
13		11.1626417	0	0	0	0	0.4412993	46.89243	-16.1373	99.3589	46.40870			

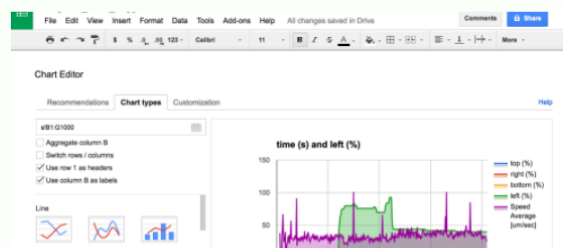
(Image copyrights: see end of course).

Go to "Insert > Chart".

The screenshot displays the Microsoft Excel interface with the 'Insert' tab selected on the ribbon. The ribbon contains the following menus: File, Edit, View, Insert, Format, Data, Tools, Add-ons, and Help. The 'Insert' menu is open, revealing several options: 'Column left', 'Column right', '6 Columns left', '6 Columns right', 'New sheet', 'Comment' (with a keyboard shortcut of $\text{Ctrl} + \text{Option} + \text{M}$), 'Note' (with a keyboard shortcut of $\text{Shift} + \text{F2}$), 'Chart...', 'Image...', 'Link...' (with a keyboard shortcut of $\text{Ctrl} + \text{K}$), and 'Form...'. The background shows a spreadsheet with a table of data. The table has columns labeled 'time (s)' and 'time (s)'. The data rows show values for 'time (s)' and 'time (s)'.

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Select "Chart types". Select "Area". Check the following boxes (in case not yet checked automatically): "Use row 1 as header" and "Use column B as labels."



Detailed instructions for graph x
You

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Select "Chart types". Select "Area". Check the following boxes (in case not yet checked automatically): "Use row 1 as header" and "Use column B as labels."

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Label the x-axis as "Time [sec]"; label the y axis as "Speed [micrometers / sec] / light intensity [a.u.]"; give the chart the title "Speed and directional light intensity over time". Finally, press "Insert" and you are done.

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CONSISTENCY CHECK - WHAT DOES YOUR GRAPH LOOK LIKE?

Your graph should look something like this (of course your actual data will be different).

Speed and directional light intensity over time

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What instruction did you follow?
(1 point possible)

☐ I used the Expert instructions.

☐ I used the Intermediate instructions.

☐ I used the Beginners instructions.

?

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Ease
(1 point possible)

How easy was it for you to make this graph?

☐ I got it right the first time.

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time [sec]

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What instruction did you follow?
(1 point possible)

☐ I used the Expert instructions.

☐ I used the Intermediate instructions.

☐ I used the Beginners instructions.

?

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Ease
(1 point possible)
How easy was it for you to make this graph?

☐ I got it right the first time.

☐ After some back and forth I eventually got it.

☐ I still don't get it even though I have looked at the Beginners instructions more than once now. I should email for help (euglena.cloudlab@gmail.com).

?

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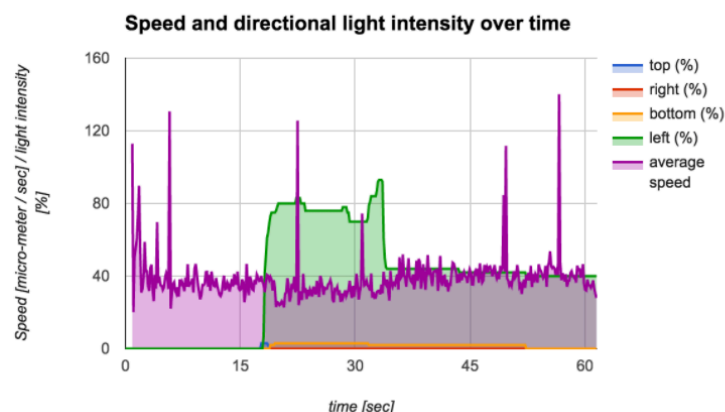
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INTERPRETING THE GRAPHICAL DATA

Now let's interpret this graph. We will start with the example here and then we will look at yours.



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Joystick position

(1 point possible)

Which statements about the joystick position during the experiment are correct? Check all that apply. (Remember: The direction you pull the joystick is where the light is coming from.)

- ☐ The joystick was always pointing in one direction at 40%
- ☐ The joystick was never pulled upwards.
- ☐ The joystick was pulled downwards a little bit at some point.
- ☐ The joystick was neutral for the first 16 seconds.
- ☐ The joystick was pulled to the right at 80% after approximately 16 seconds and then was reduced to 40% for the rest of the time.
- ☐ The joystick was pulled to the left at 80% after approximately 16 seconds and then was reduced to 40% for the rest of the time.

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Interpreting the graphical data

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Speed of Euglena
(1 point possible)

Does the speed of Euglena change when the intensity of the light changes? Use the graph above to decide.

☐ It definitely does not change.

☐ I don't think there is any change, but I am not entirely sure.

☐ It is impossible to tell - it could be argued either way.

☐ I would say there is a change, but we need more detailed analysis.

☐ It definitely does change.

?

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Compare
(1 point possible)

Now look at your own graph and data. Does the Euglena speed change when the intensity of the light changes?

☐ It definitely does not change.

☐ I don't think there is any change, but I am not entirely sure.

☐ It is impossible to tell - it could be argued either way.

☐ I would say there is a change, but we need more detailed analysis.

☐ It definitely does change.

?

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Analyze your data quantitatively and test hypotheses!
Activity

#5: Quantitative data analysis > Analyze your data quantitatively and test hypotheses! > Velocity vs. speed - and decomposition

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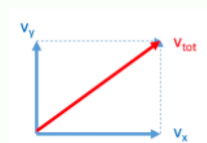
VELOCITY ALONG THE HORIZONTAL VS. VERTICAL AXIS REPRESENTATION OF DATA

Now we want you to be able to see a clear light response from the Euglena in your data. As we just established, the average speed of the Euglena does not seem to change (or at least does not change much) when the light conditions change.

But what about swimming direction?

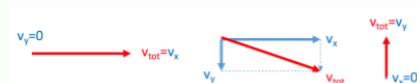
In order to study the impact of the light on the swimming direction, we need another type of data. So far we have looked only at speed - a measure of how fast something moves - but speed does not give us any information about what direction the object travels in. Velocity, on the other hand, is concerned not only with magnitude but also with direction. A direction can always be described by an arrow, where the length of the arrow corresponds to the speed.

We can decompose velocity into two components along the x and y axes, i.e. in the horizontal and vertical directions:



(Image copyrights: see end of course).

Here are some other examples of velocity decomposition. You should note that any of the velocity components can be negative (v_y in the second example) or zero (first and last example):



(Image copyrights: see end of course).

Breaking down the velocity of a Euglena into its vertical and horizontal components, we can answer not only questions about how fast the Euglena is moving overall but also in what direction it is moving faster or slower. This in turn allows us to see how light affects swimming direction.

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Choose the true statement(s)

(1 point possible)

Which of the following statements is true?

- ☐ The speed of an object is always positive or zero.
- ☐ The velocity of an object can be decomposed into a vertical and a horizontal component.
- ☐ The velocity of an object can never be negative.

Velocity | Analyze your data qu x

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Choose the true statement(s)
(1 point possible)
Which of the following statements is true?

☐ The speed of an object is always positive or zero.

☐ The velocity of an object can be decomposed into a vertical and a horizontal component.

☐ The velocity of an object can never be negative.

☐ The velocity of an object contains information about direction and magnitude.

?

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Direction of Light and Swimming
(1 point possible)
Imagine that light shines from the bottom LED. Which of the following statements is likely to be true about the swimming behavior of a collection of Euglena cells that exhibit negative phototaxis?

☐ The average velocity in the vertical direction will likely be bigger than the average velocity in the horizontal direction.

☐ The average velocity in the horizontal direction will be approximately zero.

☐ The average velocity in the vertical direction will point downwards.

☐ The average velocity in the vertical direction will be negative.

?

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Spinning Euglena
(1 point possible)
You may have observed already that some Euglena stay in one position and spin around in the xy plane when the light intensity is very strong.

Which of the following statements is true about the velocity of a single spinning Euglena? (Assume it swims in a very small circle, i.e., the speed is non-zero.)

☐ The average velocity over time in the vertical direction is non-zero.

☐ The average velocity over time in the horizontal direction is zero.

☐ The velocity in the vertical direction is oscillating over time between a positive and negative value.

☐ The velocity in the horizontal direction is always almost zero.

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Velocity components over time x

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#5: Quantitative data analysis > Analyze your data quantitatively and test hypotheses! > Dataset for velocity components

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VELOCITY COMPONENTS OVER TIME: MAKE YOUR OWN GRAPH

Now, make a single graph similar to the one before, but this time plot the two velocity components in x and y, instead of the total speed, over time. Also include the LED intensity in this graph.

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UPLOAD THE LINK TO YOUR SHEET AND GRAPH

Now upload the link to your Google Sheet document so that we can evaluate your analysis and provide you with feedback:

Go to "Share" in the upper right corner (see image).

Make sure that the option "Anyone with this link **can view**" is set to "can view" (see image)

Copy and paste the provided link into the next box

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x and y as well as light intensity over

top (%)

bottom (%)

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Copy link

https://docs.google.com/spreadsheets/d/1g502hWdN4c1VFPFdzVZu7NwV1_N8Q/

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COPY AND PASTE YOUR GOOGLE SHEET LINK ("HTTPS://DOCS.GOOGLE.COM/SPREADSHEETS/...")

(5 points possible)

If you would like feedback on your graph, indicate that in the text box as well.

Your response must be between 1 and 10000 words.

Submit Save

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Directional light response | An x

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#5: Quantitative data analysis > Analyze your data quantitatively and test hypotheses! > Plotting velocity components and interpretation

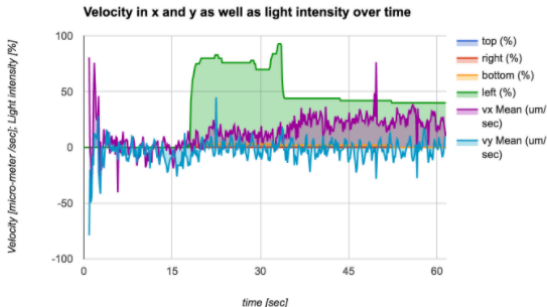
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INTERPRET THE DIRECTIONAL LIGHT RESPONSE OF EUGLENA FROM THE GRAPH

You should see a graph similar to the example below, except now you should see the velocity components in x and y instead of the total speed.

Velocity in x and y as well as light intensity over time



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Did you get the equivalent graph with your own data?
(1 point possible)

☐ Yes, I essentially got it the first time.

☐ I had to iterate a bit, but I finally got it.

☐ I think I should go back to the tutorial on how to make these graphs.

?

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Graph interpretation Q1
(1 point possible)

Looking at the example graph above, is it true or false that the average velocity in the y direction stays essentially zero independently of whether the light from the left is on or off?

☐ false

☐ true

?

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Directional light response | Answer

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Graph interpretation Q1
(1 point possible)
Looking at the example graph above, is it true or false that the average velocity in the y direction stays essentially zero independently of whether the light from the left is on or off?

☐ false

☐ true

?

SUBMITSHOW ANSWER

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Graph interpretation Q2
(1 point possible)
Again looking at the example graph above, is it true or false that the average velocity in the x direction stays essentially zero, independently of whether the light from the left is on or off?

☐ false

☐ true

?

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Behavior in your graph
(1 point possible)
Do you also see the same kind of behavior in your own graph, i.e., one of the velocity components becomes non-zero when directional light is on?

☐ Yes - clearly.

☐ No - maybe I should trouble shoot. (I will check how I plotted my data and whether there was a clear visual Euglena response when I collected the data to begin with)

?

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SECTION SUMMARY

In this section, you should have learned how to test hypotheses and how you can analyze, display, and quantify your data using Google Sheets. You should have realized that not all cells change their behavior over time, and that not all cells behave the same way; there is variability among them. This should have become evident when analyzing their speeds. You will virtually always find such variations when dealing with experimental data.

Some information only becomes apparent if plotted in a certain way. Plotting total speed did not reveal how *Euglena* respond to light, while plotting their individual velocity components did.

Congratulations - You finished section #5!

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How much time did you spend on section #5?

(1 point possible)

Time in minutes:

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Now go to section #6 (selection on the left side of the screen).

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SECTION OVERVIEW

So far we have walked you through some of the various activities that scientists do, such as

Making observations

Performing exploratory or targeted experiments

Formulating hypotheses

Collecting, analyzing, and interpreting data

Testing models

Note that these activities usually do not get executed linearly - instead there is often a back and forth, iterative process.

Now we will give you the opportunity to revisit all these steps on a small scale: you will formulate a hypothesis and then describe how you would investigate it on this online platform. It is then optional whether you want to do the full investigation or just finish the course.

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#6: The scientific method > Carry out your own investigations! > Optional - carry out your own investigations

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MAKE AN INTERESTING OBSERVATION AND DESCRIBE IT! (1 point possible)

Go back to the online microscope, play around with the light, and look for some interesting phenomenon that you would like to investigate further. This phenomenon could be anything - it does not even need to depend on light. You should hope, however, to be able to investigate this phenomenon with the tools at hand. It could also be a phenomenon that noticed earlier in the course; for example, "it seems that when I turn on the LED on one side, the Euglena moves away from it." (Don't use this example, as we have already explored it a lot in this course.)

Your response must be between 1 and 10000 words.

Submit Save

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FORMULATE A TESTABLE HYPOTHESIS AROUND THIS PHENOMENON. (1 point possible)

Example: "Euglena always moves away from light."

Your response must be between 1 and 10000 words.

Submit Save

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HOW WOULD YOU TEST THIS HYPOTHESIS? (1 point possible)

Describe what experiments and analyses you would run to test whether your hypothesis is true or not. Example: "I will initially have none of the four LEDs on for 30 seconds, then I will turn on one LED at maximum intensity for 15 seconds. I will then export the data into Google Sheets and measure the average velocities in the x and y directions before and while this LED was turned on. I will then see whether the direction of Euglena movement correlates with the direction of the light. I will then repeat the same experiment and analysis for at least two other LEDs."

Your response must be between 1 and 10000 words.

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HOW WOULD YOU TEST THIS HYPOTHESIS? (1 point possible)

Describe what experiments and analyses you would run to test whether your hypothesis is true or not. Example: "I will initially have none of the four LEDs on for 30 seconds, then I will turn on one LED at maximum intensity for 15 seconds. I will then export the data into Google Sheets and measure the average velocities in the x and y directions before and while this LED was turned on. I will then see whether the direction of Euglena movement correlates with the direction of the light. I will then repeat the same experiment and analysis for at least two other LEDs."

Your response must be between 1 and 10000 words.

Submit

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OPTIONAL: IF YOU WANT, UNDERTAKE THIS RESEARCH! (WILL PROBABLY TAKE YOU 15-60 MINUTES OR MORE)

(5 points possible)

Describe your results, your analysis, and your conclusions. Please provide a link to a Google Sheet as you have done previously, in case you have quantitatively analyzed your data (don't forget to enable us to view it). If you get some interesting research results out of your work, we will contact you and give you specific personal feedback if you like. (If you don't want to do this optional activity, then just skip this question or enter N/A.) Note: We also have a "batch experimentation mode" which makes it easier to execute many experiments; it is described in Section #2, page 3.

Your response must be between 1 and 10000 words.

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SECTION SUMMARY

In this section you revisited (deeply or superficially) some of the key tasks a scientist does.

Congratulations - You finished section #6!

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How much time did you spend on section #6?
(1 point possible)
Time in minutes:

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Final Test | Revisit what you have learned

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Revisit what you have learned!Activity

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Statement of Accomplishment

#7: Summary and feedback > Revisit what you have learned! > Final test questions

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FINAL TEST

The following questions will revisit the main content of the course. Since it is a test - your first answer counts.

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Question #1: Euglena color
(1 point possible)

Question #1: Why are Euglena cells green?

Because they eat green plant cells.

Their color is actually more brown-red but when sun light is reflected in the water it appears green.

Because they perform photosynthesis.

Because they need to hide between plant cells to escape predators.

?

FINAL SUBMITSAVESHOW ANSWER

You have used 0 of 1 submissions

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Question #2: Euglena size
(1 point possible)

Question #2: Which of the following statements about Euglena size is correct?

It is about 0.05 micro-meter long.

It is about 500 micro-meter long.

It is about 50 micro-meter long.

It is about 0.005 micro-meter long.

It is about 5 micro-meter long.

It is about 5000 micro-meter long.

It is about 0.5 micro-meter long.

?

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Question #3: Euglena speed

(1 point possible)

Question #3: What is (approximately) the fastest a Euglena cell can swim?

☐ 0.01 micro-meter / second.

☐ 10 micro-meter / second.

☐ 100 micro-meter / second.

☐ 0.1 micro-meter / second.

☐ 1000 micro-meter / second.

☐ 1 micro-meter / second.

☐ 0.001 micro-meter / second.

?

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Question #4: Euglena building blocks

(1 point possible)

Question #4: What are the three key building parts ("organelles") of a Euglena cell that enable phototaxis?

☐ Nucleus, stigma, flagellum

☐ Chloroplast, stigma, nucleus

☐ Photosensor, nucleus, flagellum

☐ Stigma, chloroplast, flagellum

☐ Flagellum, photosensor, stigma

☐ Chloroplast, photosensor, nucleus

☐ Nucleus, chloroplast, photosensor

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Questions #5: Euglena without Wobbling

(1 point possible)

Question #5: We saw that the Euglena wobbles sideways back and forth while swimming forward and also rotates around its long axis. Which of the following would be difficult to do if the Euglena rotated perfectly around its long axis without wobbling sideways? Check all that apply.

☐ Detect light from its left.☐ Detect light from its right.☐ Detect light from its back.☐ Detect light from its front.☐ React quickly to light.☐ See other Euglena.☐ Move forward.

?

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QUESTION #6: GRAPH INTERPRETATION

We have received data from a new single-celled microorganism similar to Euglena that also exhibits phototaxis. The researchers ran an experiment manipulating the direction and intensity of the light, and then measured the x- and y-components of its velocity. Here is the graph they got:



(Image copyrights: see end of course).

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WHICH OF THE FOLLOWING CONCLUSIONS CAN BE DRAWN FROM THE GRAPH ABOVE?

(1 point possible)

Check all that apply.

☐ The microorganism does not react to weak light.☐ For low light intensity, the average speed increases with light intensity.

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WHICH OF THE FOLLOWING CONCLUSIONS CAN BE DRAWN FROM THE GRAPH ABOVE?
(1 point possible)
Check all that apply.

☐ The microorganism does not react to weak light.

☐ For low light intensity, the average speed increases with light intensity.

☐ The microorganism swims towards the light for weak light intensities.

☐ The microorganism swims towards the light for strong light intensities.

☐ The microorganism exhibits both positive and negative phototaxis.

☐ The microorganism reacts stronger to light from either right or left than it reacts to the light from the top or bottom.

☐ The microorganism does not react to light intensities below 40%.

?

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Question #7: Chemotaxis
(1 point possible)
Question #7: What does "positive chemotaxis" mean?

☐ Cells moving away from light.

☐ Cells moving away from chemicals.

☐ Cells moving towards chemicals.

☒ Cells moving towards light.

?

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QUESTION #8: TWO STUDENTS HAVE BEEN DEBATING WHETHER EUGLENA SHOWS
SIGNS OF FATIGUE WHEN EXPOSED TOO LONG TO LIGHT. YOUR GOAL IS TO RESOLVE
THIS DEBATE.
(2 points possible)
What would be the exact research question? What hypothesis would you test?

Your response must be between 1 and 10000 words.

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QUESTION #8: TWO STUDENTS HAVE BEEN DEBATING WHETHER EUGLENA SHOWS SIGNS OF FATIGUE WHEN EXPOSED TOO LONG TO LIGHT. YOUR GOAL IS TO RESOLVE THIS DEBATE.

(2 points possible)

What would be the exact research question? What hypothesis would you test?

Your response must be between 1 and 10000 words.

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QUESTION #9: SAME SCENARIO AS PREVIOUS QUESTION (2 points possible)

What experiment would you suggest to run to get data to help resolve the debate?

Your response must be between 1 and 10000 words.

Submit

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QUESTION #10: HOW DO SINGLE-CELLED ORGANISMS SENSE AND NAVIGATE THEIR ENVIRONMENTS?

(2 points possible)

Explain:

Your response must be between 1 and 10000 words.

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QUESTION #11: WHAT ARE THE MAIN COMPONENTS OF THE SCIENTIFIC METHOD?

(3 points possible)

Explain:

Your response must be between 1 and 10000 words.

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Your response must be between 1 and 1000 words.

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Question #12: How much do you agree with the following statements? (1 - totally disagree; 5 - neutral; 9 - strongly agree)

(4 points possible)

Science is interesting.

?

I know what it's like to be a scientist.

?

Ordinary people can be scientists.

?

I can imagine myself as a scientist.

?

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- ▶ #3 Qualitative post-experiment data analysis
- ▶ #4: Euglena structure and control feedback for robust phototaxis
- ▶ #5: Quantitative data analysis
- ▶ #6: The scientific method

- ▼ #7: Summary and feedback

Revisit what you have learned!
Activity

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- Statement of Accomplishment

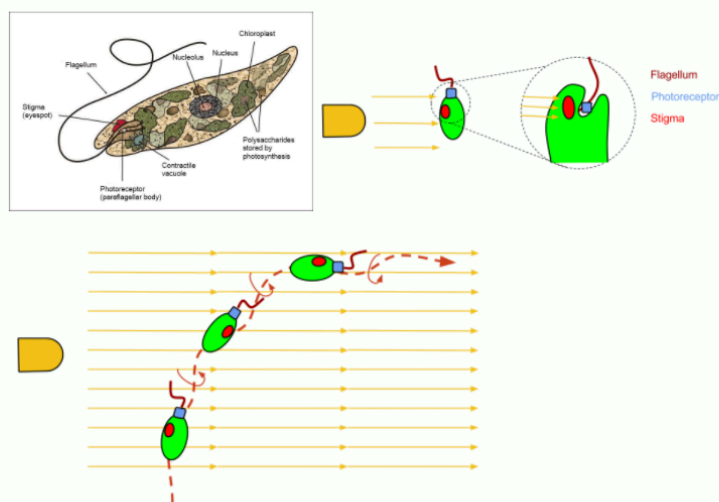
#7: Summary and feedback > Revisit what you have learned! > Course summary

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FINAL COURSE SUMMARY

We hope you have learned how *Euglena* (and many other cells) can move towards or away from light. They have a single "eyespot" to see light coming from one direction and one direction only, and they have a long flagellum that allows them to swim forward but also to rotate around their own axis. The photoreceptor is directly coupled to influence the beating pattern of the flagellum. With the right coupling strength and directionality, the cell can stably swim towards the light or away from the light. Furthermore, you should have noticed that not all cells behave exactly the same, i.e., there is variability and individuality among these microscopic cells, just as there is for macroscopic humans.



(Image copyrights: see end of course).

If you would like to know more about Euglena, start here: <https://en.wikipedia.org/wiki/Euglena>.
You are welcome to contact us for more information.

Besides this biological content itself, you should also have learned the key components of the scientific method:

1. Start with basic observations of a natural phenomenon
2. Formulate a hypothesis
3. Execute directed or even quantitative experiments to test your hypothesis
4. Look at the underlying structure of your data to come up with a qualitative explanation
5. Develop and explore a mathematical model to validate your intuition
6. Iterate! Make more observations, explore them, dive deeper, and have fun!

Press "Next" once more...

STAFF DEBUG INFO

What did you like? | Revisit wh x

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ABP G P

You

Help

Bookmarks

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Revisit what you have learned! Activity

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Statement of Accomplishment

#7: Summary and feedback > Revisit what you have learned! > Feedback

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FINALLY, PLEASE PROVIDE US WITH SOME FEEDBACK!

This will really help us to improve this course in the future!

STAFF DEBUG INFO

WHAT DID YOU LIKE?

Please state up to three things you liked in this course.

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

WHAT COULD BE IMPROVED?

Please state up to three things we could improve in this course.

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

REAL VS. SIMULATION?

Imagine that instead of the interactive microscope that you used in this course, we had provided you with an interactive simulation of Euglena instead. Here the Euglena would have been simulated similarly to what you saw during the model exploration, but those simulated Euglena would have looked more realistic and also would have displayed the range of behaviors you have observed during your real experiments. You would have been able to participate in the equivalent experimentation, data collection, and analysis activities that you engaged in during the course. In short, you would have been aware that these Euglena were simulated instead of real, but you would have done essentially the same course activities.

We are interested in your opinion on this matter, as using simulations would be much easier and cheaper to scale to large user numbers than providing a real online lab.

Please answer the following questions.

STAFF DEBUG INFO

What did you like? | Revisit wh x

You

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How would the simulation change your learning experience? Please describe.

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

To what extent would you be able to learn with the simulation? Please describe.

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

How interesting would the simulation be for you?

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

Do you think there should be a real microscope as we have provided rather than a simulation? If so - why?

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

'REALTIME EXPERIMENTATION' VS. 'SCRIPTED BATCH EXPERIMENTATION'

Besides the real-time microscope, we also offered the ability to script out an experimental stimulus

What did you like? | Revisit wh x

You

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'REALTIME EXPERIMENTATION' VS. 'SCRIPTED BATCH EXPERIMENTATION'

Besides the real-time microscope, we also offered the ability to script out an experimental stimulus protocol, submit it to the microscope, and download the data later. (You may or may not have used this feature in the course.) How would you compare the two modes regarding their usefulness?

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

Rate how useful you found the individual activities you experienced during the course (1 - not useful; 5 - neutral; 9 - very useful)
(7 points possible)

Having an online microscope with real cells.

?

Being able to stimulate cells with light in real time.

?

Being able to view the movies from your own experiments.

?

Being able to model Euglena with an interactive application.

?

Being able to download your own data and process and graph it in spreadsheets.

?

The possibility of carrying out independent investigations on this online platform.

?

Being able to execute experiments in batch mode, i.e., scripting out a LED stimulus sequence and then submitting it to the online microscope and later downloading the results.

?

What did you like? | Revisit wh x

You

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The possibility of carrying out independent investigations on this online platform.

?

Being able to execute experiments in batch mode, i.e., scripting out a LED stimulus sequence and then submitting it to the online microscope and later downloading the results.

?

SUBMIT

SHOW ANSWER

SUBMISSION HISTORY

STAFF DEBUG INFO

STAFF ANALYTICS INFO

Are you an instructor or teacher?

☐ No.

☐ Yes - middle school.

☐ Yes - high school.

☐ Yes - university or college.

☐ Yes - other not mentioned in this list.

?

SUBMIT

SHOW ANSWER

SUBMISSION HISTORY

STAFF DEBUG INFO

STAFF ANALYTICS INFO

Are you a student?

☐ No.

☐ Yes - middle school.

☐ Yes - high school.

☐ Yes - university or college.

☐ Yes - other not mentioned in this list.

?

SUBMIT

SHOW ANSWER

SUBMISSION HISTORY

STAFF DEBUG INFO

What did you like? | Revisit wh x

You

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Help

IF YOU ARE A TEACHER OR STUDENT - HOW COULD A SIMILAR OR VERY DIFFERENT COURSE BE USEFUL FOR YOU AND YOUR PEERS?

Share your thoughts, needs, specific suggestions, etc. (otherwise state N/A)

Your response must be between 1 and 10000 words.

Submit

Save

STAFF DEBUG INFO

Would you be interested / willing to be potentially contacted for a follow-up interview?

We might want to conduct, for example, a Skype interview. We would contact you via email first.

Yes (1) - No (0)

?

SUBMIT

SHOW ANSWER

SUBMISSION HISTORYSTAFF DEBUG INFO

STAFF ANALYTICS INFO

PLEASE FILL OUT THE FOLLOWING OPTIONAL POST-COURSE SURVEY TO HELP US IMPROVE THE COURSE:

STAFF DEBUG INFO

The survey will open in a new browser tab or window.

Begin Survey

STAFF DEBUG INFO

Congratulations - You finished section #6 and the course!

STAFF DEBUG INFO

How much time did you spend on section #7?

(1 point possible)

Time in minutes:

?

SUBMIT

SUBMISSION HISTORYSTAFF DEBUG INFO

What did you like? | Revisit wh x

You

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SUBMIT

SHOW ANSWER

SUBMISSION HISTORY

STAFF DEBUG INFO

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Begin Survey

STAFF DEBUG INFO

Congratulations - You finished section #6 and the course!

STAFF DEBUG INFO

How much time did you spend on section #7?
(1 point possible)
Time in minutes:

?

SUBMIT

SUBMISSION HISTORY

STAFF DEBUG INFO

STAFF ANALYTICS INFO

Go to the last section to obtain your statement of accomplishment.

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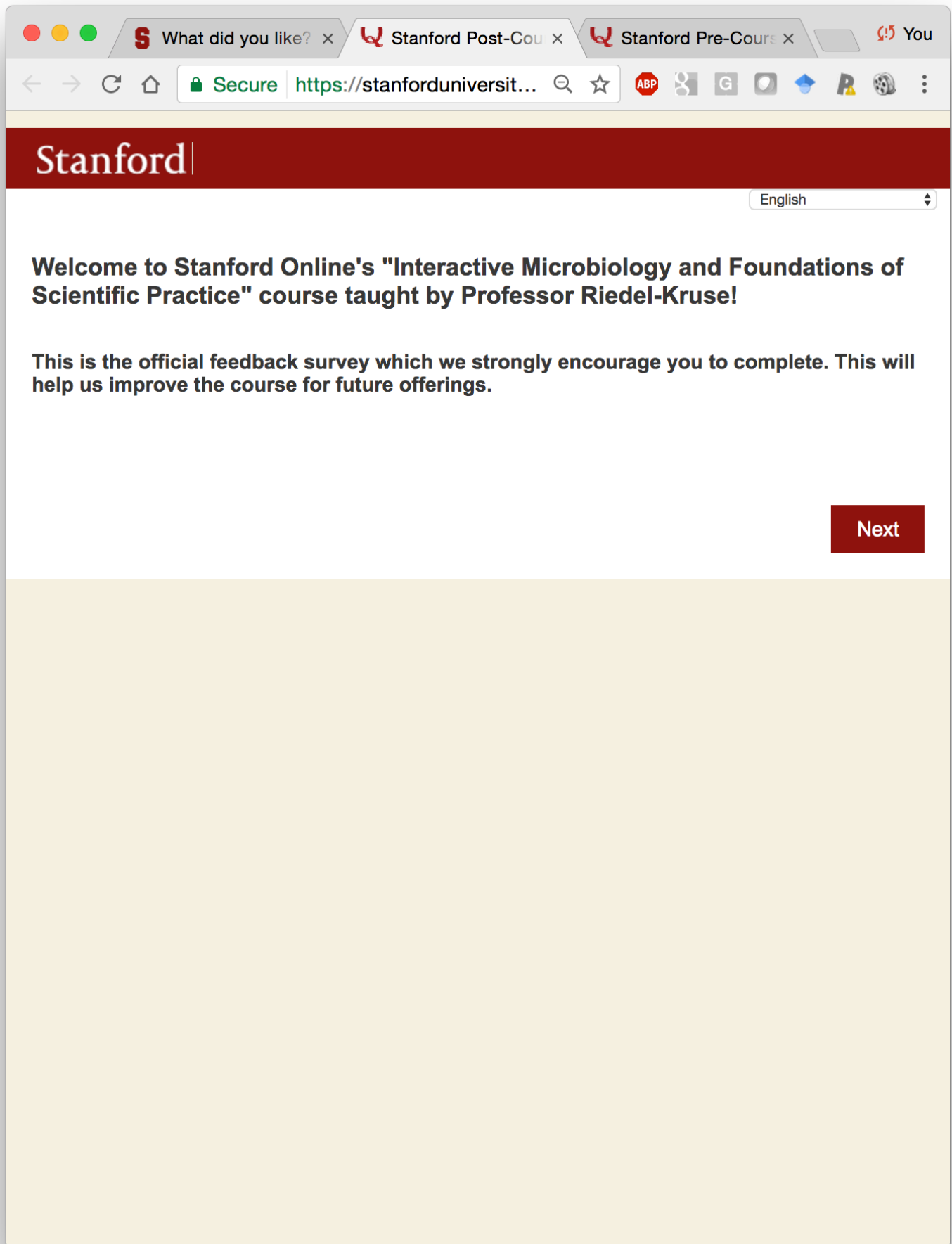
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English

Welcome to Stanford Online's "Interactive Microbiology and Foundations of Scientific Practice" course taught by Professor Riedel-Kruse!

This is the official feedback survey which we strongly encourage you to complete. This will help us improve the course for future offerings.

Next

What did you like? xStanford Post-Cou xStanford Pre-Cours xYou

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Stanford|

English

How positive or negative was your overall experience with the course?

☐ Extremely Positive

☐ Very Positive

☐ Somewhat Positive

☐ Neither Positive Nor Negative

☐ Somewhat Negative

☐ Very Negative

☐ Extremely Negative

How easy or difficult was the course?

☐ Extremely Easy

☐ Very Easy

☐ Somewhat Easy

☐ Neither Easy Nor Difficult

☐ Somewhat Difficult

☐ Very Difficult

☐ Extremely Difficult

Next

What did you like? xStanford Post-Cou xStanford Pre-Cours xYou

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How much did you learn relative to what you expected?

Much more than expected

Somewhat more than expected

Just as expected

Somewhat less than expected

Much less than expected

How likely or unlikely are you to pursue the topics further having taken this course?

Extremely Likely

Very Likely

Somewhat Likely

Neither Likely Nor Unlikely

Somewhat Unlikely

Very Unlikely

Extremely Unlikely

 Much too much guidance Too much guidance The right amount of guidance Too little guidance Much too little guidance

Next

What did you like? x

Stanford Post-Cou x

Stanford Pre-Cours x

You

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Stanford|

English

What would have been the right guidance for you? Please explain.

Next

What did you like? xStanford Post-Cou xStanford Pre-Cours xYou

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English

How much do you know about each topic now that the course is over.

	Nothing at all	A little	A moderate amount	A great deal
Microbiology	☐	☐	☐	☐
How single-celled microorganisms interact with the environment	☐	☐	☐	☐
Microorganisms as examples of sensor-actuator systems	☐	☐	☐	☐
Experimentation and hypothesis testing	☐	☐	☐	☐
Data analysis and processing	☐	☐	☐	☐
Interactive technology for biology experiments	☐	☐	☐	☐
Google Sheets	☐	☐	☐	☐

Next

What did you like? xStanford Post-Cou xStanford Pre-Cours xYou

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English

Did you experience any technical problems with the course?

No

Yes

Next

What did you like? x

Stanford Post-Cou x

Stanford Pre-Cours x

You

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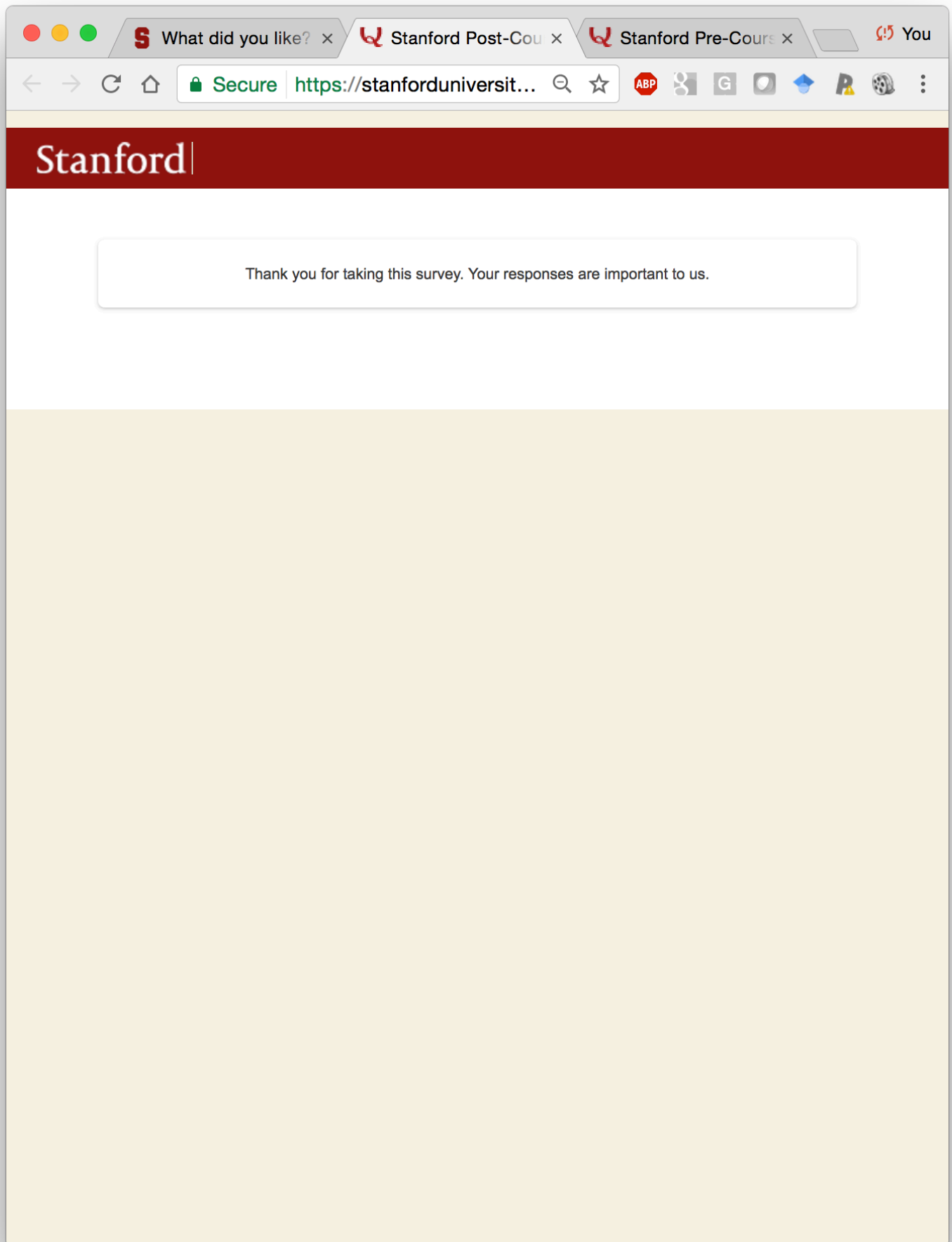
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English

What suggestions do you have for ways to improve the course when it is offered again?

Is there anything else you would like to tell us?

Next



Stanford University

Engineering: BioLab Session 6 Interactive Microbiology Session 6

demostudent

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#4: Euglena structure and control feedback for robust phototaxis

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#7: Summary and feedback

Revisit what you have learned! Activity

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Generate Your Statement of Accomplishment

Stanford University

Engineering: BioLab Session 6 Interactive Microbiology Session 6

demostudent

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Bookmarks

- #1: Cells under the microscope
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- Statement of Accomplishment
- Generate Your Statement of Accomplishment

Statement of Accomplishment > Generate Your Statement of Accomplishment > Generate Your Statement of Accomplishment

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Receiving a Statement of Accomplishment is based on having a passing score of 50% or higher in this course. You can check your score by clicking on the Progress tab in the course, which will show your overall grade.

If you have completed this course session and are satisfied with your progress, first ensure that your full name looks as you would like it to appear on the Statement of Accomplishment. Your full name in the system is currently: **Ingmar Riedel-Kruse**. If this is the name you want to use, then click on the button below to generate your Statement of Accomplishment. Otherwise, edit your full name on your [Account Settings page](#).

After you click the button below, you can go to your [account dashboard](#) and click on the "Download" button below this course's title in order to download and then print your Statement of Accomplishment.

Yes, I have completed this course.

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