

# Course introduction

Introduction

Thinking conceptually

The cell theory

Doing biology

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# Outline

## Introduction

### Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# Expectations of professor

- ▶ Start and end on time

## Expectations of professor

- ▶ Start and end on time
- ▶ Focus on conceptual understanding

## Expectations of professor

- ▶ Start and end on time
- ▶ Focus on conceptual understanding
- ▶ Make clear what terminology and facts must be learned

# Expectations of professor

- ▶ Start and end on time
- ▶ Focus on conceptual understanding
- ▶ Make clear what terminology and facts must be learned
- ▶ Open to questions – both in class (within reason) and at office hours

## Expectations of professor

- ▶ Start and end on time
- ▶ Focus on conceptual understanding
- ▶ Make clear what terminology and facts must be learned
- ▶ Open to questions – both in class (within reason) and at office hours
- ▶ Available by email and on discussion forums

## Expectations of professor

- ▶ Start and end on time
- ▶ Focus on conceptual understanding
- ▶ Make clear what terminology and facts must be learned
- ▶ Open to questions – both in class (within reason) and at office hours
- ▶ Available by email and on discussion forums

# Expectations of students

- ▶ Start and end on time

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions
- ▶ If you must talk at other times, be inobtrusive

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions
- ▶ If you must talk at other times, be inobtrusive
- ▶ **Don't use your computer in class**

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions
- ▶ If you must talk at other times, be inobtrusive
- ▶ Don't use your computer in class
- ▶ If you must use your computer in class, be inobtrusive

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions
- ▶ If you must talk at other times, be inobtrusive
- ▶ Don't use your computer in class
- ▶ If you must use your computer in class, be inobtrusive
  - ▶ And don't connect to the internet

## Expectations of students

- ▶ Start and end on time
- ▶ Print the notes from the web and bring them to class
- ▶ Don't talk while other students are talking, or while I am responding to student questions
- ▶ If you must talk at other times, be inobtrusive
- ▶ Don't use your computer in class
- ▶ If you must use your computer in class, be inobtrusive
  - ▶ And don't connect to the internet

## Structure of presentation

- Required material will be clearly outlined in the notes

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \*

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**
- ▶ General ideas and approaches presented in class may also be required; you should take notes on these in your own words

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**
- ▶ General ideas and approaches presented in class may also be required; you should take notes on these in your own words

# Why come to class?

- ▶ It's “required”

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing
  - ▶ Classroom discussion makes the course more interesting and memorable

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing
  - ▶ Classroom discussion makes the course more interesting and memorable
- ▶ Details and terminology should be covered in sufficient detail in the notes – concepts may not be

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing
  - ▶ Classroom discussion makes the course more interesting and memorable
- ▶ Details and terminology should be covered in sufficient detail in the notes – concepts may not be
- ▶ It's good to be in a biology environment a few times a week

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing
  - ▶ Classroom discussion makes the course more interesting and memorable
- ▶ Details and terminology should be covered in sufficient detail in the notes – concepts may not be
- ▶ It's good to be in a biology environment a few times a week
- ▶ Good chance to interact with other students

# Why come to class?

- ▶ It's "required"
- ▶ Listening and thinking and talking will help you understand concepts, instead of just memorizing
  - ▶ Classroom discussion makes the course more interesting and memorable
- ▶ Details and terminology should be covered in sufficient detail in the notes – concepts may not be
- ▶ It's good to be in a biology environment a few times a week
- ▶ Good chance to interact with other students

# Why read the book?

- ▶ It's interesting

# Why read the book?

- ▶ It's interesting
- ▶ The book will explain some things in a better way for you personally than I do

# Why read the book?

- ▶ It's interesting
- ▶ The book will explain some things in a better way for you personally than I do
- ▶ Familiarity improves understanding

# Why read the book?

- ▶ It's interesting
- ▶ The book will explain some things in a better way for you personally than I do
- ▶ Familiarity improves understanding

# Taking notes

- You will need to develop your own style of taking notes

# Taking notes

- ▶ You will need to develop your own style of taking notes
  - ▶ Many people benefit from writing things down, or using their own words

# Taking notes

- ▶ You will need to develop your own style of taking notes
  - ▶ Many people benefit from writing things down, or using their own words
- ▶ If a new concept is making sense to you right now, write something that will help you remember

## Taking notes

- ▶ You will need to develop your own style of taking notes
  - ▶ Many people benefit from writing things down, or using their own words
- ▶ If a new concept is making sense to you right now, write something that will help you remember
- ▶ If there's something I think you all need to write down, I will write it for you (or mark it as an answer)

## Taking notes

- ▶ You will need to develop your own style of taking notes
  - ▶ Many people benefit from writing things down, or using their own words
- ▶ If a new concept is making sense to you right now, write something that will help you remember
- ▶ If there's something I think you all need to write down, I will write it for you (or mark it as an answer)

# Evaluation

- I am responsible *only* for your midterm and exam evaluation (and only for half of that)

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes
    - ▶ and not responsible for terminology unless it's in **bold**

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes
    - ▶ and not responsible for terminology unless it's in **bold**
  - ▶ You *are* responsible for relevant ideas and concepts from lectures and readings

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes
    - ▶ and not responsible for terminology unless it's in **bold**
  - ▶ You are responsible for relevant ideas and concepts from lectures and readings
  - ▶ Conceptual questions, logical inference questions and application questions are fair game

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes
    - ▶ and not responsible for terminology unless it's in **bold**
  - ▶ You are responsible for relevant ideas and concepts from lectures and readings
  - ▶ Conceptual questions, logical inference questions and application questions are fair game
    - ▶ Practice questions will be available

# Evaluation

- ▶ I am responsible *only* for your midterm and exam evaluation (and only for half of that)
- ▶ For my content:
  - ▶ You are not responsible for details unless they are in the notes
    - ▶ and not responsible for terminology unless it's in **bold**
  - ▶ You *are* responsible for relevant ideas and concepts from lectures and readings
  - ▶ Conceptual questions, logical inference questions and application questions are fair game
    - ▶ Practice questions will be available

# Structure of presentation

- Required material will be clearly outlined in the notes

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \*

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**
- ▶ General ideas and approaches presented in class may also be required; you should take notes on these in your own words

# Structure of presentation

- ▶ Required material will be clearly outlined in the notes
  - ▶ \* This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - ▶ *This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study*
- ▶ Required terminology will be presented in **bold**
- ▶ General ideas and approaches presented in class may also be required; you should take notes on these in your own words

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts
- ▶ Facts can be observed from nature, or we can construct experiments to test specific hypotheses

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts
- ▶ Facts can be observed from nature, or we can construct experiments to test specific hypotheses
- ▶ Basic, logical thinking is very *simple*, but it is often not *easy* for humans to think clearly about abstract concepts

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts
- ▶ Facts can be observed from nature, or we can construct experiments to test specific hypotheses
- ▶ Basic, logical thinking is very *simple*, but it is often not *easy* for humans to think clearly about abstract concepts
  - ▶ *Which is more complicated: algebra or hockey?*

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts
- ▶ Facts can be observed from nature, or we can construct experiments to test specific hypotheses
- ▶ Basic, logical thinking is very *simple*, but it is often not *easy* for humans to think clearly about abstract concepts
  - ▶ *Which is more complicated: algebra or hockey?*
  - ▶ *Which are we better at thinking about?*

# Deductive thinking

- ▶ Science proceeds by advancing hypotheses and comparing them to facts
- ▶ Facts can be observed from nature, or we can construct experiments to test specific hypotheses
- ▶ Basic, logical thinking is very *simple*, but it is often not *easy* for humans to think clearly about abstract concepts
  - ▶ *Which is more complicated: algebra or hockey?*
  - ▶ *Which are we better at thinking about?*

# Algebra

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

# Hockey



# Outline

Introduction

Ground rules

Thinking conceptually

Example: cards and drinks

Logical inference

The cell theory

Doing biology

Experiments

Observational studies

# Cards



# Deductive thinking

- You go to a job interview, and are shown some playing cards.

# Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?  
Aces only; airplanes only; aces and airplanes; aces and bicycles

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
  - ▶ Some cards are face up, and you can see that they are aces or kings.
  - ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
  - ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
  - ▶ Which of the four groups of cards do you need to turn over?  
Aces only; airplanes only; aces and airplanes; aces and bicycles
- ▶ \*

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?  
Aces only; airplanes only; aces and airplanes; aces and bicycles
  - ▶ \*

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?  
Aces only; airplanes only; aces and airplanes; aces and bicycles
  - ▶ \*

# Drinks



# Deductive thinking

- You are the manager of a restaurant

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you can see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you can see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you can see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \*

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \* everybody who is drinking alcohol is of legal age

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \* everybody who is drinking alcohol is of legal age
- ▶ Which of the four groups of people do you need to check out?  
Drinkers only; older people only; drinkers and older people;  
drinkers and younger people

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \* everybody who is drinking alcohol is of legal age
- ▶ Which of the four groups of people do you need to check out?  
Drinkers only; older people only; drinkers and older people;  
drinkers and younger people
  - ▶ \*

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \* everybody who is drinking alcohol is of legal age
- ▶ Which of the four groups of people do you need to check out? Drinkers only; older people only; drinkers and older people; drinkers and younger people
  - ▶ \* Drinkers and younger people

## Deductive thinking

- ▶ You are the manager of a restaurant
- ▶ In the bar section, you can see the customers' drinks clearly, and tell whether the drinks are alcoholic or not (but not the people's ages)
- ▶ In the restaurant section, you see the customers' faces clearly, and tell whether they are underage or not (but not what they are drinking)
- ▶ You want to test the hypothesis that everything is OK:
  - ▶ \* everybody who is drinking alcohol is of legal age
- ▶ Which of the four groups of people do you need to check out? Drinkers only; older people only; drinkers and older people; drinkers and younger people
  - ▶ \* Drinkers and younger people

# Deductive thinking

- You go to a job interview, and are shown some playing cards.

# Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.

# Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?  
▶ \*

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?
  - ▶ \* The aces and the cards with bicycles on the back

## Deductive thinking

- ▶ You go to a job interview, and are shown some playing cards.
- ▶ Some cards are face up, and you can see that they are aces or kings.
- ▶ Some cards are face down, and you can see whether they have bicycles or airplanes on the back
- ▶ The interviewer asks you to test the hypothesis that all of the aces have airplanes on the back
- ▶ Which of the four groups of cards do you need to turn over?
  - ▶ \* The aces and the cards with bicycles on the back

# Thinking conceptually

- Logical interpretation and inference is simple, but not always easy

# Thinking conceptually

- ▶ Logical interpretation and inference is simple, but not always easy
  - ▶ This is true for everyone

# Thinking conceptually

- ▶ Logical interpretation and inference is simple, but not always easy
  - ▶ This is true for everyone
- ▶ Being on familiar ground helps us think clearly

# Thinking conceptually

- ▶ Logical interpretation and inference is simple, but not always easy
  - ▶ This is true for everyone
- ▶ Being on familiar ground helps us think clearly
  - ▶ This will work for different people in different ways: learning facts, stories, mechanisms, etc.

# Thinking conceptually

- ▶ Logical interpretation and inference is simple, but not always easy
  - ▶ This is true for everyone
- ▶ Being on familiar ground helps us think clearly
  - ▶ This will work for different people in different ways: learning facts, stories, mechanisms, etc.
- ▶ Practice clear thinking about simple questions

## Thinking conceptually

- ▶ Logical interpretation and inference is simple, but not always easy
  - ▶ This is true for everyone
- ▶ Being on familiar ground helps us think clearly
  - ▶ This will work for different people in different ways: learning facts, stories, mechanisms, etc.
- ▶ Practice clear thinking about simple questions

# Outline

Introduction

Ground rules

Thinking conceptually

Example: cards and drinks

Logical inference

The cell theory

Doing biology

Experiments

Observational studies

# Inference

- ▶ Does the last statement *follow* from the first two?

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \*

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.
  - ▶ \*

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.
  - ▶ \* Valid conclusion

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.
  - ▶ \* Valid conclusion
  - ▶ \*

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.
  - ▶ \* Valid conclusion
  - ▶ \* Based on the assumptions

# Inference

- ▶ Does the last statement *follow* from the first two?
- ▶ Cats have four legs. Mammals have four legs. *Therefore*, cats are mammals
  - ▶ \* Not a valid conclusion
- ▶ Cows can fly. Dushoff is a cow. *Therefore*, Dushoff can fly.
  - ▶ \* Valid conclusion
  - ▶ \* Based on the assumptions

Valid conclusion



# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons
  - ▶ Pigeons can be trained to do remarkably complicated things with their bills to get food

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons
  - ▶ Pigeons can be trained to do remarkably complicated things with their bills to get food
  - ▶ and with their feet to avoid electric shocks

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons
  - ▶ Pigeons can be trained to do remarkably complicated things with their bills to get food
  - ▶ and with their feet to avoid electric shocks
  - ▶ **but not the other way around!**

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons
  - ▶ Pigeons can be trained to do remarkably complicated things with their bills to get food
  - ▶ and with their feet to avoid electric shocks
  - ▶ but not the other way around!
- ▶ Why does this make sense?

# Why are simple things difficult?

- ▶ Probably because we are *adapted* specifically to be good at certain kinds of thinking
- ▶ Example: training pigeons
  - ▶ Pigeons can be trained to do remarkably complicated things with their bills to get food
  - ▶ and with their feet to avoid electric shocks
  - ▶ but not the other way around!
- ▶ Why does this make sense?

## Assignment: Logical equivalence

- Are these two statements logically equivalent?

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall
- ▶ Are these two statements logically equivalent?

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall
- ▶ Are these two statements logically equivalent?
  - ▶ Good food is not cheap

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall
- ▶ Are these two statements logically equivalent?
  - ▶ Good food is not cheap
  - ▶ Cheap food is not good

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall
- ▶ Are these two statements logically equivalent?
  - ▶ Good food is not cheap
  - ▶ Cheap food is not good
- ▶ Consider this an assignment

## Assignment: Logical equivalence

- ▶ Are these two statements logically equivalent?
  - ▶ Tall people are mean
  - ▶ Mean people are tall
- ▶ Are these two statements logically equivalent?
  - ▶ Good food is not cheap
  - ▶ Cheap food is not good
- ▶ Consider this an assignment

# Logical equivalence

- Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways
  - ▶ Can you construct an example where one is true and the other is false?

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways
  - ▶ Can you construct an example where one is true and the other is false?
  - ▶ What would it take for each statement to be true?

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways
  - ▶ Can you construct an example where one is true and the other is false?
  - ▶ What would it take for each statement to be true?
  - ▶ **What would it take to falsify each statement?**

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways
  - ▶ Can you construct an example where one is true and the other is false?
  - ▶ What would it take for each statement to be true?
  - ▶ What would it take to falsify each statement?
  - ▶ **Can I construct a parallel example that I can relate to?**

# Logical equivalence

- ▶ Statements are **logically equivalent** if they express the same fact in different words. In other words, if either one is true, the other one must be true.
  - ▶ And vice versa
- ▶ Different people find it useful to think about logical equivalence in different ways
  - ▶ Can you construct an example where one is true and the other is false?
  - ▶ What would it take for each statement to be true?
  - ▶ What would it take to falsify each statement?
  - ▶ Can I construct a parallel example that I can relate to?

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# All living organisms are composed of cells

- ▶ A **cell** is a highly organized compartment bounded by a membrane

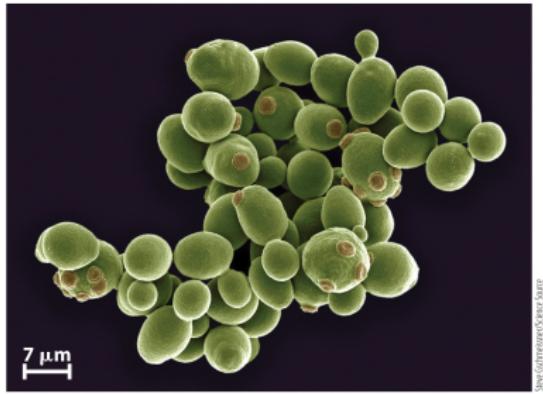


Figure 1.16b  
Biology: How Life Works  
© Macmillan Learning

# All living organisms are composed of cells

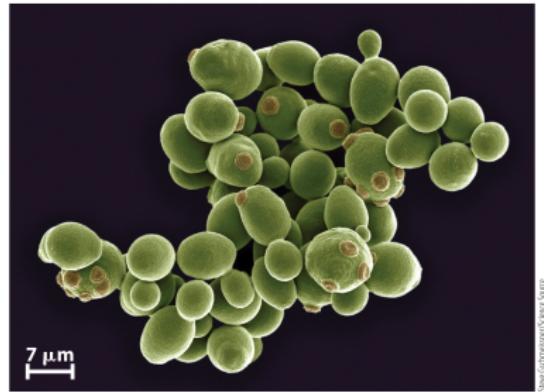


Figure 1.16b  
Biology: How Life Works  
© Macmillan Learning

- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes made of DNA**

# All living organisms are composed of cells



- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes** made of **DNA**
- ▶ **Proteins** made of **amino acids**

# All living organisms are composed of cells

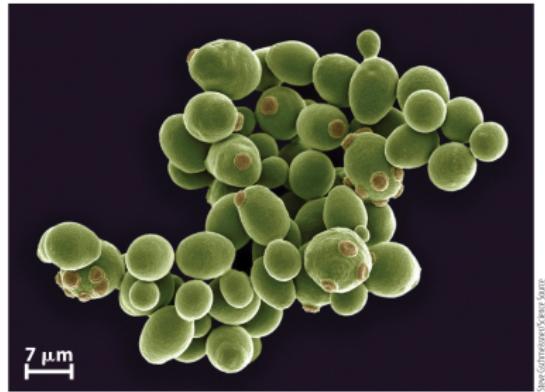
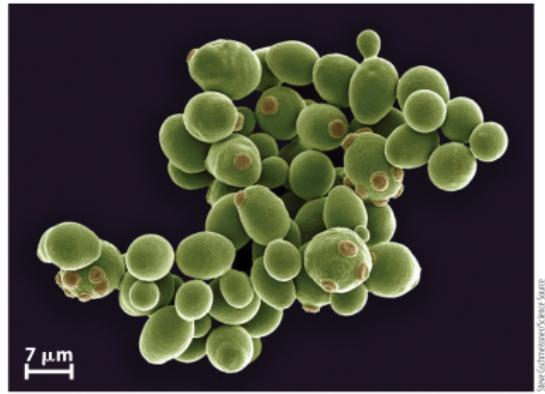


Figure 1.16b  
Biology: How Life Works  
© Macmillan Learning

- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes** made of **DNA**
- ▶ **Proteins** made of **amino acids**
- ▶ *What about viruses?*

# All living organisms are composed of cells



- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes** made of **DNA**
- ▶ **Proteins** made of **amino acids**
- ▶ *What about viruses?*
  - ▶ *No cells*

# All living organisms are composed of cells

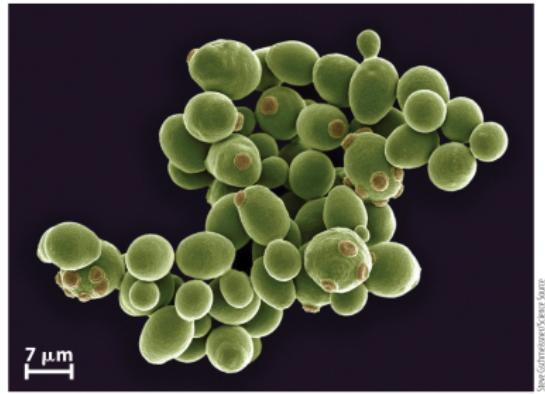


Figure 1.16b  
Biology: How Life Works  
© Macmillan Learning

- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes** made of **DNA**
- ▶ **Proteins** made of **amino acids**
- ▶ *What about viruses?*
  - ▶ *No cells*
  - ▶ *Typically not defined as living organisms*

# All living organisms are composed of cells

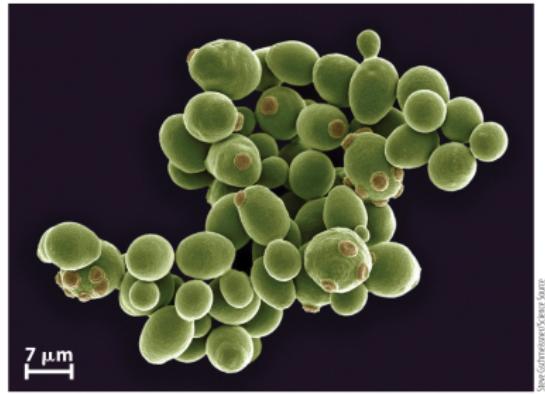


Figure 1.16b  
Biology: How Life Works  
© Macmillan Learning

- ▶ A **cell** is a highly organized compartment bounded by a membrane
- ▶ **Genes** made of **DNA**
- ▶ **Proteins** made of **amino acids**
- ▶ *What about viruses?*
  - ▶ *No cells*
  - ▶ *Typically not defined as living organisms*

## Cells (see textbook)

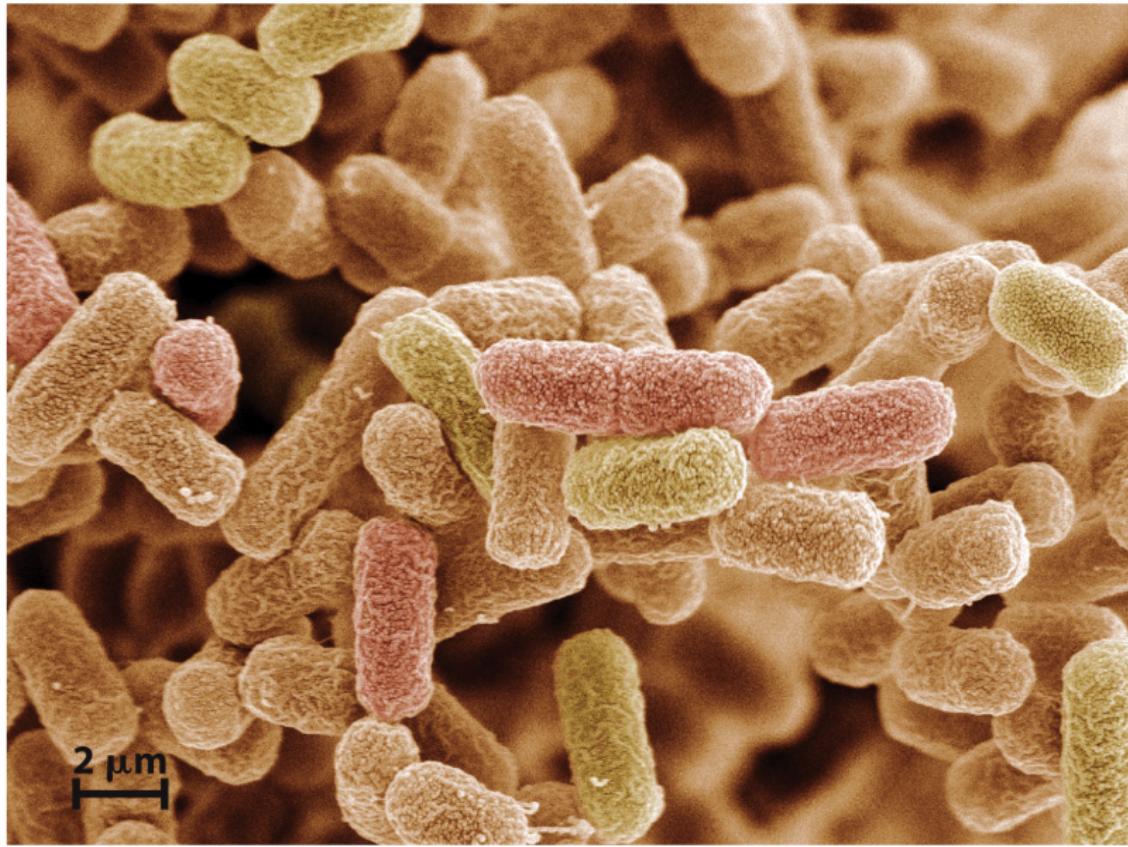


Figure 1.9a  
*Biology: How Life Works*

Steve Gschmeissner/Science Source

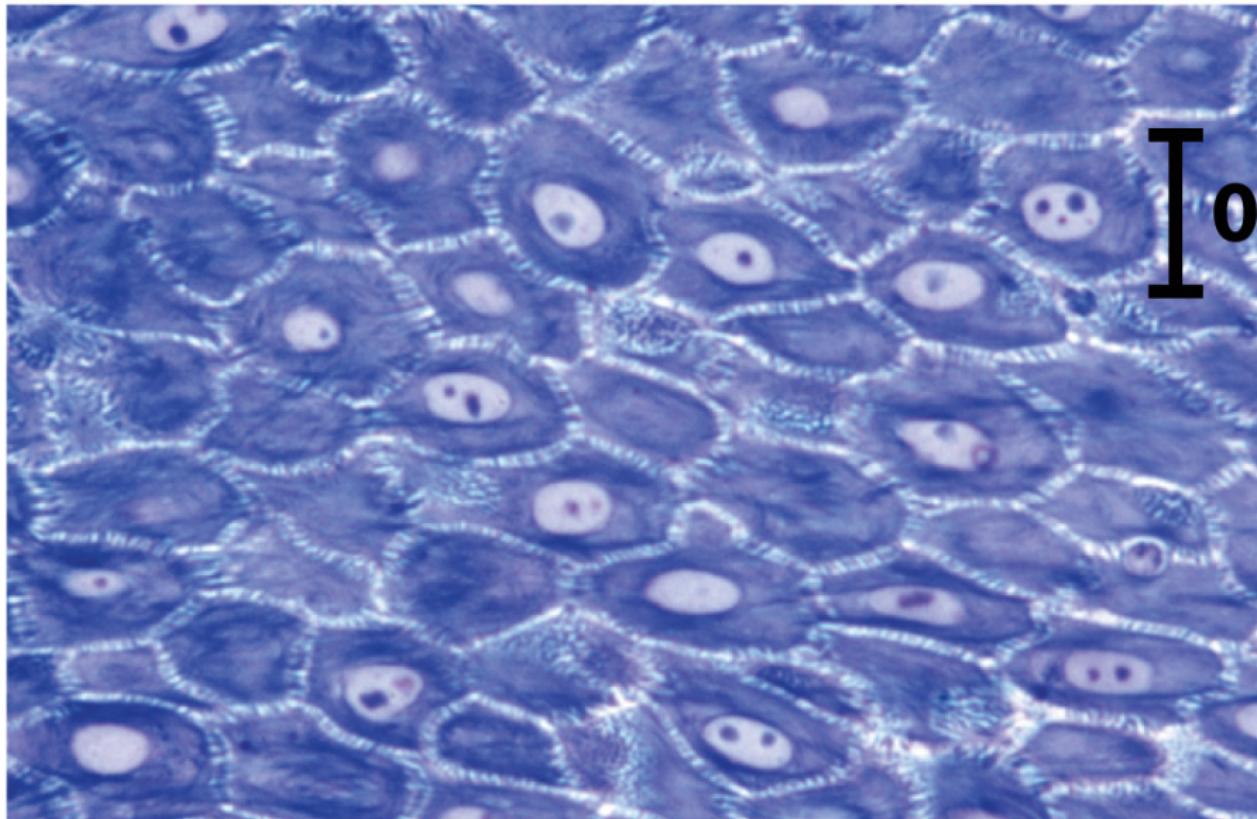


## Cells (see textbook)



Figure 1.9d  
Biology: How Life Works

Cells (see textbook)



10

Figure 1.10a  
Biology: How Life Works

# Where do cells come from?

- Are they generated spontaneously?

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear
- ▶ Do they come only from other cells?

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear
- ▶ Do they come only from other cells?
  - ▶ \*

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear
- ▶ Do they come only from other cells?
  - ▶ \* Then where did the first cells come from?

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear
- ▶ Do they come only from other cells?
  - ▶ \* Then where did the first cells come from?
- ▶ *The origin of early cells is a big research topic, including here at Mac!*

# Where do cells come from?

- ▶ Are they generated spontaneously?
  - ▶ If we leave damp bread out, molds just appear
- ▶ Do they come only from other cells?
  - ▶ \* Then where did the first cells come from?
- ▶ *The origin of early cells is a big research topic, including here at Mac!*

# Where do flies come from?

► Is this just craziness?

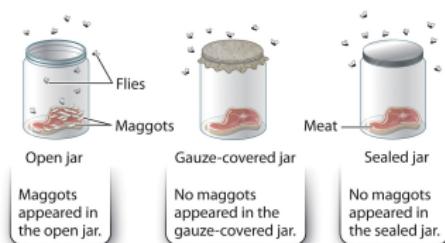


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?

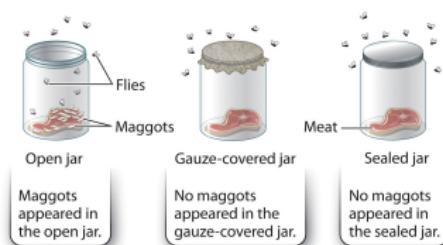


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?

▶ \*

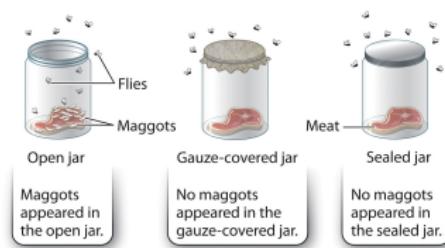


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?

▶ \*

- ▶ Why three jars?

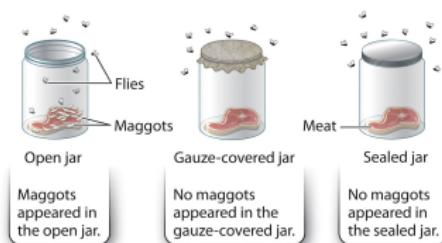


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?

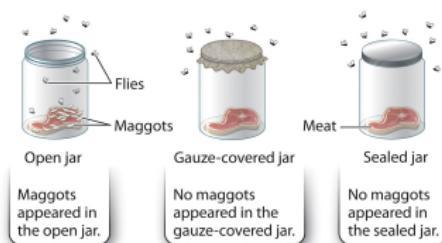


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?

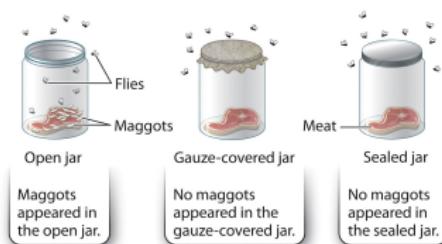


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?



- ▶ Any concerns?

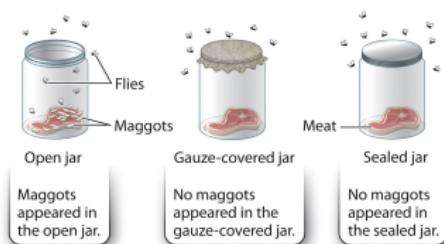


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?



- ▶ Any concerns?

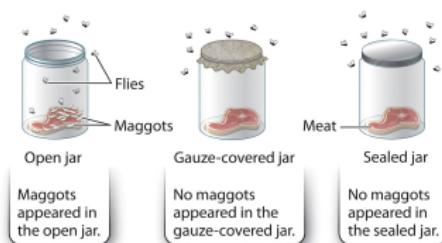


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?



- ▶ Any concerns?

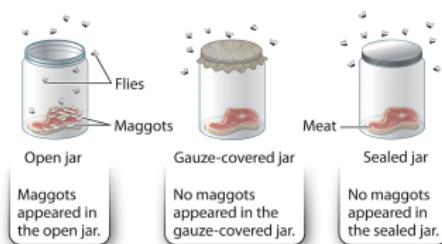


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do flies come from?

- ▶ Is this just craziness?



- ▶ Why three jars?



- ▶ Any concerns?

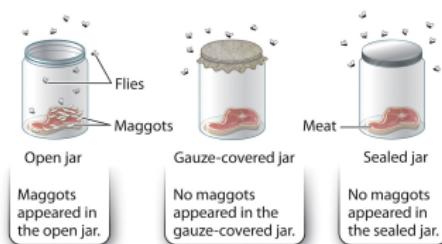
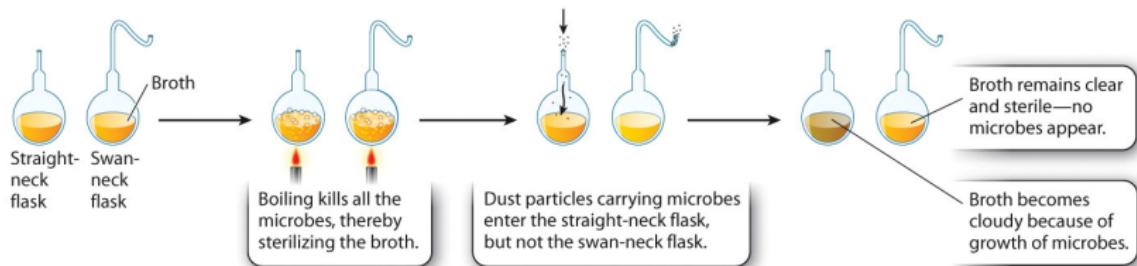


Figure 1.7  
© 2010 Pearson Education, Inc., or its affiliates. All Rights Reserved.

# Where do microbes come from?



**Figure 1.8**  
*Biology: How Life Works*  
© Macmillan Learning

# Where do microbes come from?

- Why was it necessary to have two flasks?

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?

## Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \* Maybe cells can generate spontaneously under other conditions

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \* Maybe cells can generate spontaneously under other conditions
  - ▶ \*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \* Maybe cells can generate spontaneously under other conditions
  - ▶ \* . . . , but that's not what's happening here

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \* Maybe cells can generate spontaneously under other conditions
  - ▶ \* . . . , but that's not what's happening here
- ▶ *Hold up one finger if you want to finish copying blue stuff*

# Where do microbes come from?

- ▶ Why was it necessary to have two flasks?
- ▶ What if the first flask had also failed to grow cells?
  - ▶ \* Maybe the broth wasn't the right kind to support growth of cells
  - ▶ \* Maybe the flask was somehow poisonous or discouraging
  - ▶ \* It's the *contrast* that's convincing
- ▶ Does this prove all cells come from cells?
  - ▶ \* Maybe cells can generate spontaneously under other conditions
  - ▶ \* ...., but that's not what's happening here
- ▶ *Hold up one finger if you want to finish copying blue stuff*

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# Hypotheses

- We pursue science by evaluating **hypotheses** (sing., hypothesis). These are proposed explanations of facts.

# Hypotheses

- ▶ We pursue science by evaluating **hypotheses** (sing., hypothesis). These are proposed explanations of facts.
- ▶ We use hypotheses to make predictions, and use experiments and observations to attempt to **falsify** hypotheses – to prove they are false.

# Hypotheses

- ▶ We pursue science by evaluating **hypotheses** (sing., hypothesis). These are proposed explanations of facts.
- ▶ We use hypotheses to make predictions, and use experiments and observations to attempt to **falsify** hypotheses – to prove they are false.
  - ▶ Most hypotheses cannot be *proved* to be true, instead, if we fail to falsify them, we say that they are supported

# Hypotheses

- ▶ We pursue science by evaluating **hypotheses** (sing., hypothesis). These are proposed explanations of facts.
- ▶ We use hypotheses to make predictions, and use experiments and observations to attempt to **falsify** hypotheses – to prove they are false.
  - ▶ Most hypotheses cannot be *proved* to be true, instead, if we fail to falsify them, we say that they are supported
  - ▶ If a hypothesis explains many facts, and survives attempts at falsification, we tend to believe it

# Hypotheses

- ▶ We pursue science by evaluating **hypotheses** (sing., hypothesis). These are proposed explanations of facts.
- ▶ We use hypotheses to make predictions, and use experiments and observations to attempt to **falsify** hypotheses – to prove they are false.
  - ▶ Most hypotheses cannot be *proved* to be true, instead, if we fail to falsify them, we say that they are supported
  - ▶ If a hypothesis explains many facts, and survives attempts at falsification, we tend to believe it

# Scientific inquiry (see textbook)

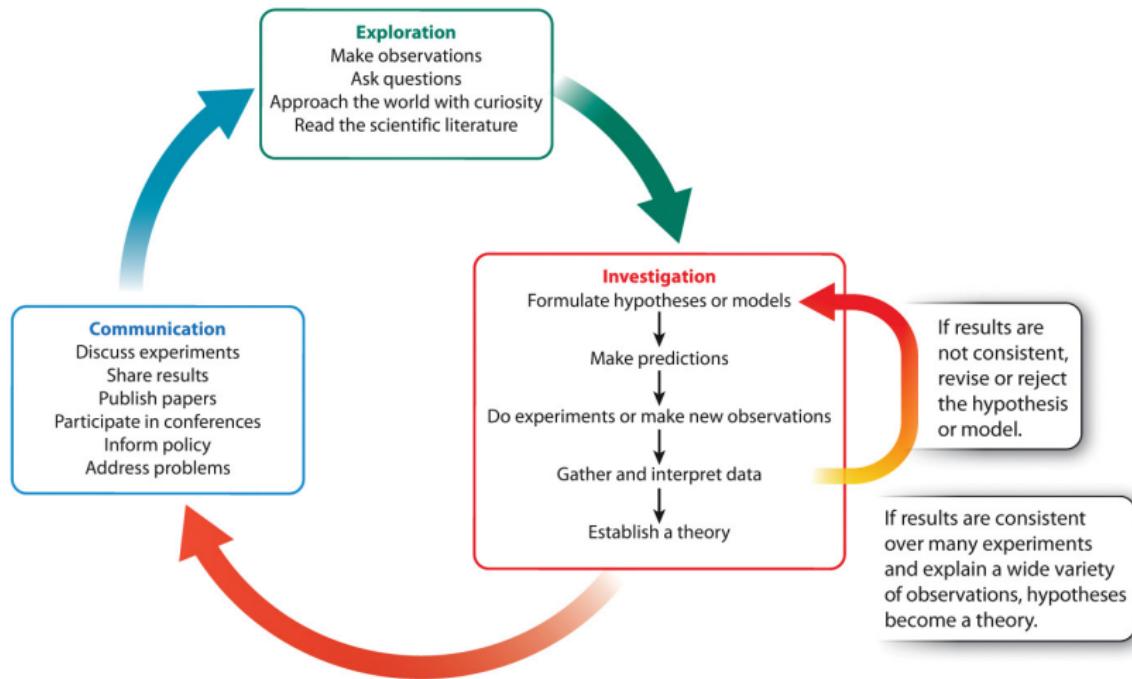


Figure 1.2

Biology: How Life Works  
© Macmillan Learning

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ **What is wrong with this experiment?**

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \*

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \*

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.
- ▶ \*

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.
- ▶ \* What if I compare two mice?

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.
- ▶ \* What if I compare two mice?
  - ▶ \*

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.
- ▶ \* What if I compare two mice?
  - ▶ \* one will always do better than the other!

## Example: Vitamin C

- ▶ I want to find out whether Vitamin C is good for mice, so I raise a mouse on a standard diet, with Vitamin C supplement, to see whether it has a long, happy, healthy life.
- ▶ What is wrong with this experiment?
  - ▶ \* No comparison. I don't know how the mouse would have done in the absence of the supplement
  - ▶ \* I only used one mouse. I don't know if there was something unusual about it.
- ▶ \* What if I compare two mice?
  - ▶ \* one will always do better than the other!

# Control

- Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ **Can you think of a problem?**

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \*

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \* Treatment mice all get caught and stuck with needles

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \* Treatment mice all get caught and stuck with needles
- ▶ A solution?

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \* Treatment mice all get caught and stuck with needles
- ▶ A solution?
  - ▶ \*

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \* Treatment mice all get caught and stuck with needles
- ▶ A solution?
  - ▶ \* Give the control mice injections with no vaccine

# Control

- ▶ Good experiments are **controlled**: we have two or more groups that differ only in some factor we want to study
  - ▶ flask neck, vitamin C
- ▶ Groups should be as similar as possible, except for the factor that we wish to study
- ▶ Example: I want to see how injecting a particular vaccine affects mouse behaviour
- ▶ Can you think of a problem?
  - ▶ \* Treatment mice all get caught and stuck with needles
- ▶ A solution?
  - ▶ \* Give the control mice injections with no vaccine

## Replication

- Good experiments are **replicated**: each treatment group has more than one **replicate**

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask

## Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).

## Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?

## Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \*

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages

## Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages
  - ▶ \*

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages
  - ▶ \* Maybe one cage is colder, or gets a lot of glare

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages
  - ▶ \* Maybe one cage is colder, or gets a lot of glare
  - ▶ \*

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages
  - ▶ \* Maybe one cage is colder, or gets a lot of glare
  - ▶ \* Maybe one cage has a bad social dynamic

# Replication

- ▶ Good experiments are **replicated**: each treatment group has more than one **replicate**
  - ▶ A replicate is a unit which is subjected to a chosen treatment
    - ▶ e.g., a mouse, a troop of baboons, a flask
- ▶ Replicates should be **independent**. Replicates in the same group should not have *anything* in common that they don't share with other groups (except for the factor we are studying).
- ▶ POLL What if we put all the mice that get vitamin supplements in one cage, and the others in another cage?
  - ▶ \* We then have to worry about all possible differences between the two cages
  - ▶ \* Maybe one cage is colder, or gets a lot of glare
  - ▶ \* Maybe one cage has a bad social dynamic

# Randomization

- Good experiments are **randomized**: units are assigned to treatments randomly

# Randomization

- ▶ Good experiments are **randomized**: units are assigned to treatments randomly
  - ▶ First, arrange the experiment

# Randomization

- ▶ Good experiments are **randomized**: units are assigned to treatments randomly
  - ▶ First, arrange the experiment
  - ▶ e.g., first pick which mice to put into which cages, *then* decide at random which cages get supplements

# Randomization

- ▶ Good experiments are **randomized**: units are assigned to treatments randomly
  - ▶ First, arrange the experiment
  - ▶ e.g., first pick which mice to put into which cages, *then* decide at random which cages get supplements

# Where do flies come from? (see textbook)



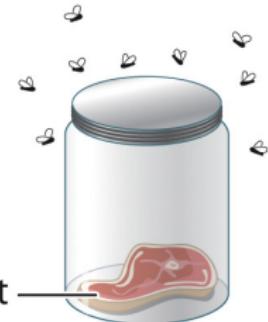
Open jar

Maggots  
appeared in  
the open jar.



Gauze-covered jar

No maggots  
appeared in the  
gauze-covered jar.

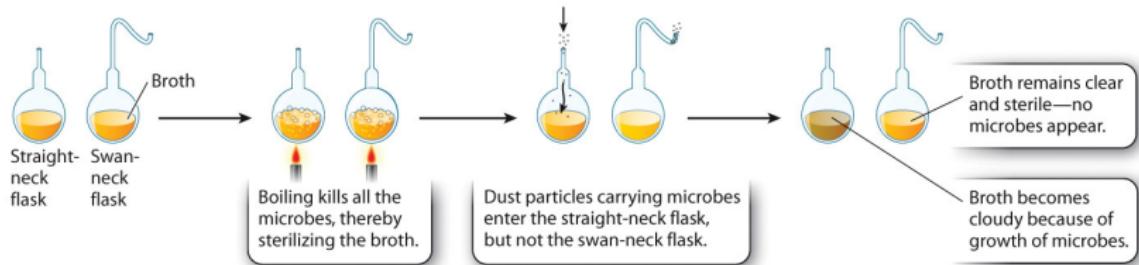


Sealed jar

No maggots  
appeared in  
the sealed jar.

Figure 1.7  
*Biology: How Life Works*  
© Macmillan Learning

# Where do microbes come from? (see textbook)



**Figure 1.8**  
*Biology: How Life Works*  
© Macmillan Learning

# Outline

## Introduction

Ground rules

## Thinking conceptually

Example: cards and drinks

Logical inference

## The cell theory

## Doing biology

Experiments

Observational studies

# Observational studies

- Look for ways to collect data that will support or challenge hypotheses

## Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies

## Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \*

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \*

## Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?
  - ▶ \*

## Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?
  - ▶ \* You can't always do experiments

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?
  - ▶ \* You can't always do experiments
  - ▶ \*

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?
  - ▶ \* You can't always do experiments
  - ▶ \* Time, practicality, ethics

# Observational studies

- ▶ Look for ways to collect data that will support or challenge hypotheses
- ▶ Scientists are cautious about making conclusions from observational studies
  - ▶ \* It's hard to know if you've taken everything into account
  - ▶ \* Experiments are more reliable ...
- ▶ So why do we do them?
  - ▶ \* You can't always do experiments
  - ▶ \* Time, practicality, ethics

# Dinosaurs (see textbook)

At Gubbio, Italy, the recessed clay layer in the center of the photo (arrow) marks the end of the Cretaceous Period, when many species became extinct. As shown in the diagram on the right, this layer shows strong enrichment in iridium, rare in most rocks on Earth but relatively common in meteorites.



Andrew Knoll, Harvard University

**Figure 1.3 (Part 1a)**  
*Biology: How Life Works*  
© Macmillan Learning

## Dinosaurs (see textbook)

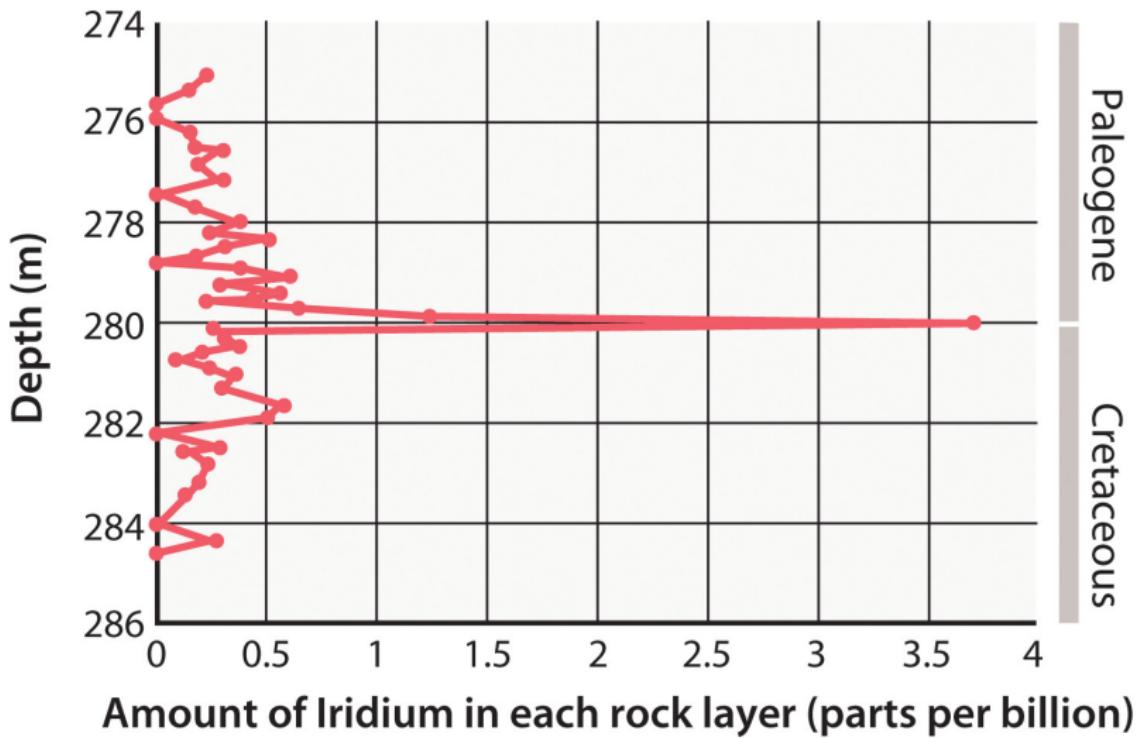
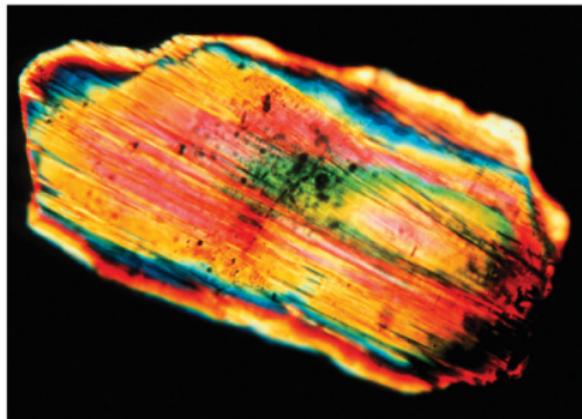


Figure 1.3 (Part 1b)  
Biology: How Life Works  
© Macmillan Learning

## *Dinosaurs (see textbook)*

Quartz crystals that form only at high temperature and pressure—conditions met by giant meteors as they crash into Earth—occur abundantly in rock layers dated to the time of the extinction.



Dr. David King/Science Source

**Figure 1.3 (Part 2a)**  
*Biology: How Life Works*  
© Macmillan Learning

## *Dinosaurs (see textbook)*

By 1990, geologists had located a crater of just the right size and age in the Yucatan Peninsula, Mexico (image to the right created by mapping subtle variations in Earth's gravitational field).



**Figure 1.3 (Part 2b)**  
*Biology: How Life Works*  
© Macmillan Learning

# Dinosaurs

- Why did the dinosaurs go extinct?

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?

▶ \*

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \*

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \*

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \*

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \* Don't be ridiculous

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \* Don't be ridiculous
- ▶ *Are* the dinosaurs extinct?

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \* Don't be ridiculous
- ▶ Are the dinosaurs extinct?
  - ▶ \*

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \* Don't be ridiculous
- ▶ Are the dinosaurs extinct?
  - ▶ \* We will come back to this!

# Dinosaurs

- ▶ Why did the dinosaurs go extinct?
  - ▶ \* *Probably* a meteor
  - ▶ \* Evidence in book is not all that we have
  - ▶ \* No replication, no control!
- ▶ Can we test this with an experiment?
  - ▶ \* Don't be ridiculous
- ▶ Are the dinosaurs extinct?
  - ▶ \* We will come back to this!

# Assignment: Car Trouble

- A brother calls his sister because something is wrong with his car

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:
  - ▶ Sister: I have a tow hitch, and a tow rope, but I obviously can't tow you.

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:
  - ▶ Sister: I have a tow hitch, and a tow rope, but I obviously can't tow you.
  - ▶ Brother: That's OK, I can tow *you*!

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:
  - ▶ Sister: I have a tow hitch, and a tow rope, but I obviously can't tow you.
  - ▶ Brother: That's OK, I can tow *you*!
  - ▶ Sister: I guess so. If we're careful.

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:
  - ▶ Sister: I have a tow hitch, and a tow rope, but I obviously can't tow you.
  - ▶ Brother: That's OK, I can tow *you*!
  - ▶ Sister: I guess so. If we're careful.
- ▶ Each person drives their own car. Nothing is wrong with the sister's car. What is wrong with the brother's car?

## Assignment: Car Trouble

- ▶ A brother calls his sister because something is wrong with his car
- ▶ She arrives, and they have this conversation:
  - ▶ Sister: I have a tow hitch, and a tow rope, but I obviously can't tow you.
  - ▶ Brother: That's OK, I can tow *you*!
  - ▶ Sister: I guess so. If we're careful.
- ▶ Each person drives their own car. Nothing is wrong with the sister's car. What is wrong with the brother's car?

# More logic

- ▶ Whatever doesn't kill you makes you stronger

## More logic

- ▶ Whatever doesn't kill you makes you stronger
- ▶ If we take this literally, then: Whatever doesn't make you stronger ...

## More logic

- ▶ Whatever doesn't kill you makes you stronger
- ▶ If we take this literally, then: Whatever doesn't make you stronger ...
  - ▶ \*

## More logic

- ▶ Whatever doesn't kill you makes you stronger
- ▶ If we take this literally, then: Whatever doesn't make you stronger ...
  - ▶ \* kills you

## More logic

- ▶ Whatever doesn't kill you makes you stronger
- ▶ If we take this literally, then: Whatever doesn't make you stronger ...
  - ▶ \* kills you