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ABSTRACT: To the learner, the language of genetics is filled with complicated terminology and jargon that experts take for granted. To successfully learn major genetics concepts, students must master these idiomatic and often confusing terms. Specifically, research has shown that students have difficulty fully understanding the nature of chromosomes, which are arguably an essential genetic concept. For example, students may believe that a condensed metaphase chromosome is a pair of chromosomes. Given that textbooks are a common reference source for students, we reviewed 6 current texts for the words and concepts found in various textbook features used to describe the term chromosome. Our preliminary analysis revealed significant inconsistencies and deficiencies across the textbooks. Glossary definitions varied in several ways: one did not include the fact that chromosomes contain DNA; another did not include the term chromosome; one text did not have a glossary at all. The indexes contained between 20–101 headings and sub-headings for the term chromosome, frequently with no page number indicated for the actual term. Even when a page number was indicated, the definition found on that page was not descriptive; one text defined chromosomes as “discrete structures” of DNA. Additionally, figures of chromosomes included photomicrographs and drawings of replicated, unreplicated, condensed, and uncondensed chromosomes; and, there was variation in the inclusion of terms such as allele, sister chromatid, and homologous chromosomes in associated figure captions. Our in-depth analysis of textbook features used to describe the chromosome and related terms (i.e., chromatid) will be presented. We will also suggest ways in which textbook features might be modified to enhance both the teaching and learning of genetics. As a ubiquitous teaching tool, the textbook is an ideal place to begin addressing fundamental misunderstandings in genetics. This analysis, in combination with investigations into student understanding using concept inventories and other authentic assessment measures, will contribute to the improved student learning of important genetic concepts.

1. THE PROBLEM

The structure and function of the chromosome is arguably one of the most fundamental concepts in genetics for students to understand. Undergraduate student responses to concept questions regarding the chromosome, reveal that the majority of students (54-74%) have a basic grasp of chromosomes and homologues; however, they cannot apply their knowledge within the context of other concepts, such as allele (Table 1)*. Since the textbook is a common source of information and explanations for students, we embarked on a content analysis of textbook information and images. Similar analyses have been done with a focus on high school texts (2, 4, 6, 8).

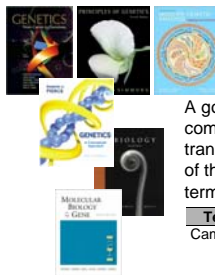
Table 1.

QUESTION TEXT	n	CORRECT ANSWER	MOST COMMON DISTRAC(T)OR(S)
When chromosomes are drawn as an X structure, each of the lines in the X represent	318	identical sister chromatids (73.9%)	homologous chromosomes (22.2%)
Which of the following is true of homologous chromosomes?	139	They are inherited from different parents (61.2%)	They contain identical DNA sequences (36.5%)
If an organism is diploid and has 16 chromosomes, how many sets of homologous chromosomes does it possess?	318	8 (53.7%)	32 (24.7%) 16 (20.5%)

QUESTION TEXT	n	CORRECT ANSWER	MOST COMMON DISTRAC(T)OR(S)
Below are drawings that represent the chromosomes within a cell undergoing meiosis; alleles are labeled. Which drawing correctly illustrates a cell with two different alleles for a single gene?	274	E (22.6%)	A, B, C, D, F

2. THE QUESTION

What information and images are found in textbooks regarding the concept of chromosomes?



3. METHODS

We analyzed chromosome glossary definitions, index references, and images in 6 major textbooks. For each content area, we asked these questions:
Glossary: *Is there a helpful definition?*
Index: *Does it lead students to page(s) that clearly explain the concept?*
Figures: *Are the images illustrative, explanatory and/or complementary to the concept?*

4. ANALYSIS OF GLOSSARIES

A good definition of chromosome should address: 1) its chemical composition, 2) that it contains genes, and 3) that it is the vehicle for transmission of genetic information. Based on these criteria, only two of the four textbooks with glossary definitions adequately defined the term chromosome (Table 2).

Text ¹	Definition	Composition	Genes	Transmission
Campbell	A thread-like, gene-carrying structure found in the nucleus. Each chromosome consists of one very long DNA molecule and associated proteins. See chromatin.	✓	✓	
Griffiths	A linear end-to-end arrangement of genes and other DNA, sometimes associated with protein and RNA	✓	✓	✓
Hartwell	The self-replicating genetic structures of cells containing the DNA that carries in its nucleotide sequence the linear array of genes	✓	✓	
Snustad	Darkly staining nucleoprotein bodies that are observed in cells during division. Each chromosome carries a linear array of genes	✓	✓	✓

¹ Pierce had no definition in the glossary and Watson does not contain a glossary.

6. ANALYSIS OF INDEXES

Our minimum expectation for index entries was that they should explicitly direct the student to a good definition in the text. Of the six books we analyzed, only three did so (Table 4). Textbooks varied in the number of headings and sub-headings suggesting that chromosomes range from marginally important (17 entries; Watson) to very important (64 entries; Pierce).

Table 4.

Text	Number of sub-headings
Campbell	28 ¹
Griffiths	56
Hartwell	40
Pierce	64
Snustad	18 ¹
Watson	17 ¹

¹ Index contained an explicit direction to a page number w/ definition.

7. CONCLUSIONS

Informed by student misconceptions about chromosomes, we could analyze textbooks from both novice and expert perspectives. We identified features which may contribute to students' misconceptions, such as: incomplete or missing glossary definitions and indexes with too many sub-headings or lack of direction to a definition in the text. The use of complementary images that promote active learning provides an opportunity to enrich the learning experience; however, few texts utilize them. Below are shown examples of images of chromosomes from texts with a proposed option for helping students better understand various confusing or troublesome aspects chromosomes. In sum, given the importance of the text as a source of information for students, their structure and composition warrants careful attention.

Below are examples of potentially confusing images of chromosomes. Banding patterns and genes are both represented as horizontal lines, chromosomes are frequently shown as replicated, condensed chromosomes (perhaps because this is the way we visualize them). However, this form of the chromosome is transient during a cell's life.

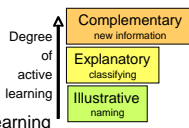


We analyzed textbooks according to Pozzer and Roth (2003). They categorized figures in several ways that we found useful:

Illustrative: names the phenomenon

Explanatory: names and classifies the phenomenon

Complementary: names the object/phenomenon; contains new information not available in the associated text; requiring active learning

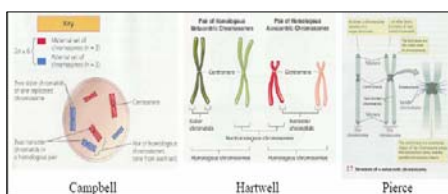


Texts varied in the number and percentages of figures in each category, with most texts containing mostly explanatory figures (Table 3). Campbell's figures of chromosomes were entirely complementary. Examples of illustrative images found with chromosome text were: the great lubber grasshopper, a teenager with Down Syndrome, and the Francis Ford Coppola family. These types of images are not essential and may actually distract, especially in the absence of good explanatory and/or complementary images.

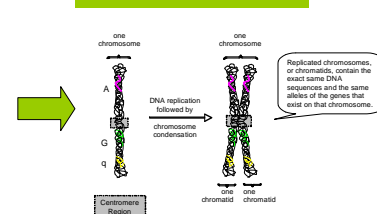
Table 3.

Textbook	Chapter/Section Title	Figure Search Area	Total pages searched	Number of figures	Figures per page	Categories ¹		
						Illustrative	Explanatory	Complementary
Campbell	Sets of Chromosomes in Human Cells	240-1	2	4	2	0%	0%	100%
Griffiths	The Nature of Eukaryotic Chromosomes	41-48	8	16	2	44%	44%	12%
Hartwell	Chromosomes Contain the Genetic Material	81-88	8	6	0.75	25%	25%	50%
Pierce	Chromosomes and Cellular Reproduction	21-23	3	4	1.3	0%	100%	0%
Snustad	Chromosomes: Where Genes are Located	19-21	3	2	0.6	0%	100%	0%
Watson	Genome Structure, Chromatin, and the Nucleosome	135-8	4	3	0.75	0%	100%	0%

¹ After Pozzer and Roth, 2003



Better



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*See #384/T for a complementary poster on using diagnostic question clusters to identify and address misconceptions about chromosomes, alleles, the central dogma, and the ubiquity of genetic material.