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Article

Increasing undergraduate student interpreters' fluency and accuracy in interpreting STEM content

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Abstract: Interpreters who are skilled in interpreting science, technology, engineering, and mathematics (STEM) content fluently and accurately are few and far between. This issue is particularly true at the post-secondary level. Those interpreters who are available often do not have command of the vocabulary needed to interpret more specialized content and rely heavily on letter-for-letter fingerspelling and word-for-word transliteration. This project looked at the knowledge of the principles of fingerspelling on undergraduate student interpreters' ability to interpret typical introductory biology lecture material accurately and fluently. Research involved modifying a signing bioscience dictionary (SBD), developing life science content summaries, creating videos of fingerspelling principles, and conducting an evaluation. Key findings showed participants' knowledge of bioscience vocabulary was significantly improved with use of the SBD and that their ability to interpret typical biology lecture material fluently and accurately improved. After watching the videos and learning to apply the principles of fingerspelling, their fingerspelling scores also improved significantly. However, there was no significant improvement in biology content knowledge.

Keywords: syllabication; science interpreting; ASL science vocabulary; fingerspelling

1. Introduction

Research shows that deaf or hard-of-hearing (DHH) students are underrepresented in occupations that require majoring in a STEM field (Listman and Dingus-Eason, 2018). Researchers Marchut and Gormally (2019) as well as Vesel and Robillard (2022) suggest factors contributing to this issue are that many DHH students do not have a science identity or an understanding of the range of STEM occupations available to them with a STEM major. They also note that most DHH students do not have real world experience with scientists who are deaf to guide them along the path to becoming a STEM professional.

Other researchers attribute low enrolment of DHH students in STEM courses to the need for accommodations and to an absence of mentors who are themselves deaf (Braun et al., 2018). For DHH students to be successful in STEM courses, independent of the language used (sign or spoken), a range of accommodations are required. Gehret et al. (2021) found that in lab situations hearing researchers prefer to communicate with DHH students in writing while DHH students prefer to use interpreters and communicate in sign. Braun et al. (2018) investigated the doctoral experiences of DHH students who were successful in their study of STEM. They found that having mentors that were either deaf or aware of Deaf culture and who could themselves sign were seen as the most effective for progress in STEM areas. These mentors were perceived as providing the necessary social capital (Bourdieu, 1986) to enable them to function effectively in a hearing world (Braun et al., 2018; Marchut and Gormally, 2019). Types of social capital mentioned included navigational capital (knowing how to maneuver in a hearing world), aspirational capital (role models that were themselves either deaf or supportive of deaf students), and resistance capital (strength to challenge systemic inequities). These types of social capital were referred to by Listman and Dingus-Eason (2018) as Deaf Cultural Capital (learning how to advocate for accommodations, such as having interpreters at conferences or in the lab and having both aspirational and resistance capital to continue in stressful situations).

Another factor leading to under representation of students in STEM fields is a lack of qualified sign language interpreters with knowledge of STEM content or who have STEM-related interpreter training or interpreting experience (Grooms, 2015; Grooms et al., 2012). Those interpreters who are available may fail to make the language “visible” or comprehensible and may rely heavily on letter-for-letter fingerspelling and word-for-word transliteration, thereby rendering STEM courses minimally accessible (Seal et al., 2002; Powell et al., 2014). To address this situation, Vesel and Clark (2019) focused on training signed language interpreting students to see if learning vocabulary related to biology increased their ability to fluently interpret a traditional lecture. They found that despite improvement in both knowledge of bioscience vocabulary and the ability to sign it, study participants were unable to effectively follow the pace of a typical bioscience lecture. They made many sign-production errors, used signs that were not conceptually accurate, used almost no classifiers, and were unable to set up items in a spatial grammar (Vesel and Clark 2019; Vesel, Clark, and Robillard, 2020). Evaluating these findings showed that the lecture included many fingerspelled words, which slowed down or threw off the participants. Those who did manage to fingerspell the vocabulary correctly, tended to look like they were typing, ignoring how syllabification and coarticulation work.

Most people are unaware of how syllabification or coarticulation work or even what they mean. Syllabification is the plan to organize syllables into larger pronounceable units and includes both ‘pronunciation’ and the ‘metrical structure’ that produces the emphasis used in pronunciation (Traxler, 2012, p. 41). For example, the word “escorting” has two morphemes, the root escort and the suffix-ing. When people actually pronounce the word escorting, they usually produce it in three segments (not the two morphemes), “which sound something like … ess-core-ting rather than ess-cort-ing” (p. 41). Notice the ‘t’ is pronounced with the suffix, -ing, rather than with cort. Therefore, syllabification “intervenes between morphological processing and articulation” (Traxler, 2012, p. 41) altering pronunciation rather than simply activating morphemes. These effects are related to speech planning (Traxler, 2012) and lead to the speaker creating “rhythmic, pronounceable metrical structures that largely ignore lexical word boundaries” (p. 42). Coarticulation can also occur with changes in the production of a sign segment due to letters or phonemes that come before or after what is signed. This usage is how native signers encode fingerspelling and why it is important to look at the movement envelop rather than trying to identify individual letters. Coarticulation in sign creates a fluent movement based on what comes before and after each sign segment. These effects occur in all languages, regardless of whether they are signed or spoken.

Given that most interpreters are functioning in a language that is not their first language but rather in a second or third language and that most faculty in signed language interpreting programs are hearing, this linguistic structure of sign languages and especially fingerspelling is rarely if ever taught in the classroom. There is also limited research in this area, except for Van Manen's (2018) book, titled "The fingerspelling code: Linguistics of the ASL alphabet" and an earlier study, titled "The phonetics of fingerspelling" (Wilcox, 1994). In his short monograph, Wilcox begins to consider the possibility of a native signer's fingerspelling as an array of distinct hand movements. Almost a quarter century passes before this topic receives further attention. Van Manen, in his book, describes the linguistic principles that alter fingerspelling, changing it from a typewriter experience to one that is based on syllabication and coarticulation. The research, described in this article, is the first to examine integration of this linguistic structure into the teaching of students studying to be interpreters.

Based on this prior research, the study described in this paper incorporated video-based training on these processes and its use with terms included in the SBD, which was augmented with summaries of core bioscience content. The following research questions provided insight into use and effectiveness of these components: 1) How do Lamar undergraduate students use the SBD and biology content summaries? 2) How effective are the SBD and content summaries in increasing Lamar undergraduate students' ASL bioscience vocabulary and bioscience content knowledge? 3) How effective are the videos in increasing Lamar undergraduate ASL students' capacity to fingerspell terms and to interpret typical undergraduate bioscience lecture material accurately and fluently? 4) What additions and/or changes would make the materials more effective?

In the next section, we describe the features of the SBD, provide details about the content summaries, and explain the principles of fingerspelling that are incorporated into the videos and the application of these principles to STEM vocabulary.

1.1. Key elements of the revised signing bioscience dictionary (SBD)

Development of a revised version of the SBD focused on identification of terms that required adjustment and pinpointing those within definitions that require understanding to comprehend the meaning of the definition. Terms within definitions were then incorporated into the interface and hyperlinked to their respective SBD pages. The navigation bar interface was also modified. An additional component of development involved integration of elements of universal design into the interface. Users can view the selected SBD videos in sign with or without captions or listen in English with or without simultaneous sign or voice overlay. They can also exercise the option to increase or decrease text size, loudness, and contrast, and play and replay all or part of the video as often as needed (Vesel et al., 2022). **Figure 1** provides an example of a term page, definition, access to the terms below definitions, and interactive features available.

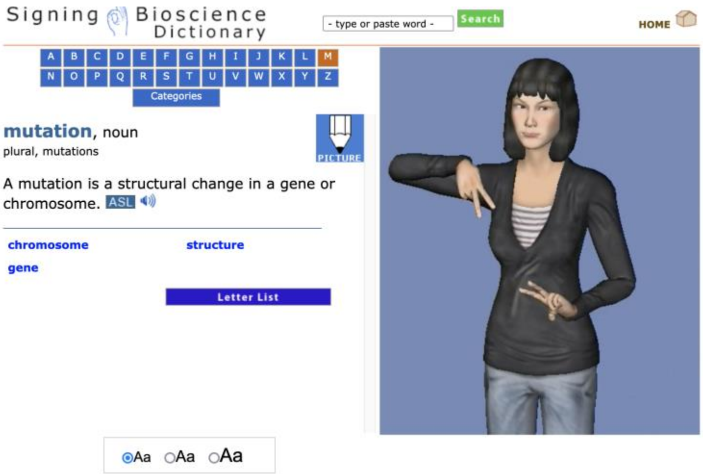

Figure 1. An example of an SBD page.

1.2. Key elements of the content summaries

Development of summaries of key bioscience content involved identifying topics that emerged from review of the definitions and terms included in the categories incorporated into the SBD interface. This resulted in identification of cell structure and function, genes and heredity, ecology and ecosystems, and skills of scientific investigation as the focus of the summaries. The most recent edition of Campbell Biology (Urry et al., 2020), the text used in Lamar's undergraduate biology courses, plus material and images that the TERC team had researched and developed previously and that had been reviewed by experts, were used to ensure accuracy.

1.3. Key elements of the fingerspelling videos

To address the finding from earlier research related to students' inability to interpret typical bioscience lecture material accurately and clearly, the Lamar team produced videos explaining the linguistic principles of fingerspelling and the application of these principles of syllabication or coarticulation to the fingerspelling of terms included in the SBD. This involved Lamar researchers, who are deaf native signers, conducting an analysis of implicit fingerspelling rules and use of the strategies for teaching effective fingerspelling as presented in James W. Van Manen's book. The linguistic principles that were the focus of the videos are as follows: unimorph, which is the blending of two letters (e.g., when fingerspelling the word apple, the -LE allomorphs are fused into one smooth motion); synomorph, where two phonological features occur synchronously (e.g., for the word silver, the letters S and I are produced synchronously); bimorph, where two letters in a word are blended together (e.g., oil, the I-L are blended together); trimorph, where three phonological features happen in one movement (e.g., in the word pizza, the allomorphs P-I-Z-Z are articulated in one smooth motion); and as quadmorph, where four letters are merged (e.g., in the word deafhood, the allomorphs for O in H-O-O-D are blended). The two resulting videos explain each of these five principles and provide a review of them using examples from the SBD. **Figure 2** provides example pages from the videos.

(a)

(b)

Figure 2. Fingerspelling videos, **(a)** an example of a fingerspelling principles page; **(b)** an example of a fingerspelling principles review page.

2. Data and methods

Evaluation involved a two-phase study focusing on the SBD category of Genes and Heredity. This category was selected because many of the terms in it must be fingerspelled. An example indicating the type of content included in this category is provided as an Appendix.

Methods followed

Experimental design—Research incorporated a pre-post mixed measurement design that combines qualitative and quantitative methods in which the outcome of interest is measured for participants only. It did not include a control sample.

Study sample—The results of a power analysis of the number required to detect a medium effect size, indicated that we needed a target number of approximately 25 students to detect a medium treatment effect. Recruitment involved the posting of flyers throughout Lamar's Department of Deaf Studies and Deaf Education (DSDE) program area and instructors announcing the opportunity in their classes. These recruitment methods resulted in a final sample of 24 ASL interpreting students who volunteered to participate.

The demographics of the undergraduate DSDE interpreting student participants are shown show below. Imbalances in characteristics of the study population, such as gender, year in the program, and ethnicity, reflect imbalances in the overall population of DSDE students and were unavoidable. They also reflect imbalances that exist in the population of interpreters working in the field. **Table 1** provides students' demographics.

Table 1. Demographic information of study participants (N = 24).

Ethnicity	White-14 Latino/Hispanic-5 African American/Black-1 American Indian-1 Asian American-2 Other-1
Gender	Female-23 Male-1
Year in program	Year 1–7 Year 2–6 Year 3–8 Year 2–4 Not reported-1
ASL proficiency level	Novice-3 Survival-4 Intermediate-11 Advanced-5 Superior-1

Data collection procedures—Data collection was divided into two parts. Phase I examined participants' study and mastering of the SBD vocabulary included in the category and related content. Phase II examined participants' learning and being able to use syllabication or coarticulation in signed fingerspelling. The data collection procedures for Phase I mirror those used for a previous study that examined DSDE interpreting students' ability to use and master SBD vocabulary incorporated into a prototype SBD (Vesel, Clark, and Robillard, 2020) The prototype provided the foundation for development of the version of the SBD described in section 1.1. The Phase I procedures are summarized below. Additional detail is provided in the 2020 article. The data collection procedures used for phase II are new and not available in the earlier publication. Examples of the instruments used for each phase are provided after discussion of the phase II data collection procedures.

Phase I data collection procedures—This involved four sessions each of which provided data that was systematically analyzed and evaluated in the context of the research questions described above. For the first session, Institutional Review Board (IRB) requirements for working with human subjects were completed and participants' data, including items such as age, gender, and level in the DSDE program were gathered. Baseline information about participants' SBD vocabulary content knowledge and ability to sign a subset of terms in the genes and heredity category was also assembled. This provided quantitative phase I pre-test data for comparison with post-test data.

For the second and third sessions, participants were introduced to the features of the SBD. They then independently practiced signing terms in the genes and heredity category and used the information incorporated into the definitions to learn their meaning. Researchers watched and logged their observations. This provided qualitative information for subsequent integration into analysis of the phase I quantitative data.

For the fourth session, participants demonstrated their SBD vocabulary content knowledge and ability to sign a subset of terms in the genes and heredity category after use of the SBD. This provided quantitative phase I post-test data for comparison with pre-test data that was used to determine effectiveness of the revised SBD. They also filled out an online survey that provided quantitative and qualitative data about their SBD experiences and suggestions for its improvement.

Phase II data collection procedures—This involved five sessions that yielded quantitative and qualitative pre- and post-test data. During the first session participants were asked to fingerspell 15 of the SBD terms included in the genes and heredity category of the SBD as a pre-test. A research team member then showed them the videos explaining the principles of fingerspelling and answered their questions. Guided by a research team member, the second, third, and fourth sessions involved participants in individual study of each principle by practicing its fingerspelling across a range of terms. Researchers observed each participant at work and completed an observation form.

The fifth session was an evaluation of their fluency. It involved participants in fingerspelling the terms included in the pre-test and in completing a post interpreting sample that was the same as that used for the pre-test in phase I. The pre- and post-fingerspelling and interpreting sample were recorded. Then, the pre- and post-use videos were analyzed to determine if participants' fingerspelling fluency had increased and if they had applied the principle(s) to their fingerspelling.

The following tables provide examples of instruments used for data collection—**Table 2** is the Phase I matching vocabulary pre- and post-test page, **Table 3** is the phase I observation form page, **Table 4** is the student participant survey page, **Table 5** is the phase II observation form page.

Table 2. An example of a phase I matching vocabulary pre- and post-test page.

A.	**Do you know how to sign this word?**		
B.	**How would you interpret this word?**		
Vocabulary		**A. Sign**	**B. Interpret**
1.	chromosome	CHROMOSOME	Separate body unit. find in cell. Look-like exact group fs-genes. In long fs-dna protein. Best see process mitosis meiosis.
2.	clone	COPY	One ancestor-person their gene, cell, live-thing, stole copy.
3.	deoxyribonucleic acid	fs-DNA	Plan info look-like chromosome named double fs-helix. In live-thing their gene. In 3listfs-deoxyribose, fs-phosphate group, fs-adenine, fs-gaunine, fs-cytosine, fs-thymine
4.	gene	Fs	Important part. do 5list info group pass-down. Describe info for specific characteristics gene. Where? chromosome there.

fs = fingerspell.

Table 3. An example of a phase I observation form page.

1) How are the tools introduced?
2) How do participants begin and proceed to use the tools?—i.e., where do they start, how do they decide which h
3) Describe what participants are doing and saying as they click on terms and view the signed terms/definitions. Include examples of questions, responses, and statements.
4) What features do participants use when they access the signed terms?
5) What are participants' reactions/actions in response to the tools?

Table 4. An example of a student participant survey page.

1) How easy for you was it to find information in the signing dictionary?
2) How easy was it for you to use the signing dictionary and content summaries?
3) How helpful were the dictionary and summaries?
4) How did you use the dictionary?
5) How did you look at words?
6) How did you look at definitions?
7) Which features did you use?
8) How did you find terms in the signing dictionary?
9) If you were unable to find something, was it because…
10) Would you like to use the dictionary again?
11) Using the signing dictionary was fun.
12) Using the signing dictionary made it easier to learn science words and definitions.
13) Using the signing dictionary and summaries helped me to learn on my own.
14) Did you use the dictionary to learn new signs?
15) Did you use the dictionary and summaries to learn the meaning of a word that you did not know or were not sure about?
16) Please indicate how satisfied you were with each of the following:
Information available for each term
Accuracy of the signs
Understanding the avatar
Avatar's facial expressions
17) What do you like about the dictionary and content summaries?
18) What do you dislike about the dictionary and content summaries?

Table 5. An example of a phase II observation form page.

1) Did the participant know the fingerspelling principles prior to watching the video?
2) Had the student already taken the fingerspelling course offered at LU?
3) When watching the videos, what behavior did you observe from the participant? (e.g., copying the examples on their own hand, taking notes, requesting pause and review, passive watching)?
4) As you paused the video to provide further explanation to the participant, did the participant have clarifying or follow up questions?
5) Upon completion of the video, was the participant able to explain the principles of fingerspelling?

3. Results

Statistical analysis—Data preparation involved exporting the data, removing identifiers from the data sources, and implementing a numerical identification system for tracking data. Data from each source were arranged in spreadsheets, using Statistical Packages for Social Science Software (SPSS). Quantitative data were analyzed using descriptive and correlational analyses to answer our research questions. Qualitative data were analyzed using a content analysis. To identify additions and/or changes, we tabulated recommendations from surveys and observation data into spreadsheet lists organized according to categories.

Paired samples statistics for knowledge of ASL bioscience vocabulary as evidenced by students' ability to sign terms (=ghpre, ghpost), interpret a sample lecture (=intpre, intpost), match terms and their definitions (=matpre, matpost), and fingerspell terms (=prefinger, postfinger) are shown in **Table 6**.

Table 6. Paired samples statistics.

		Mean	Standard deviation	Mean standard error
Pair 1	ghpre	8.229	13.771	2.811
	ghpost	36.562	14.528	2.965
Pair 2	intpre	2.417	5.358	1.094
	intpost	12.500	14.014	2.860
Pair 3	matpre	21.500	16.138	3.294
	matpost	23.333	16.252	3.318
Pair 4	prefinger	9.833	5.958	1.216
	postfinger	11.645	6.200	1.266

Paired differences for knowledge of bioscience vocabulary (=ghpre-ghpost), interpreting a sample lecture (=interpre-intpost), matching terms and their definitions (=matpre-matpost), and fingerspelling terms (=prefinger-postfinger) are shown in **Table 7**. Confidence interval of the difference and significance are shown in **Table 8**.

Table 7. Paired differences.

		Mean	Standard deviation	Standard mean error
Pair 1	ghpre-ghpost	−28.333	17.054	3.481
Pair 2	intpre-intpost	−10.083	12.913	2.635
Pair 3	matpre-matpost	−1.833	16.915	3.452
Pair 4	prefinger-postfinger	−1.812	4.894	0.999

95% confidence interval significance.

Table 8. Confidence interval of the difference and significance.

		Lower	Upper	*t*	df	One-sided *p*	Two-sided *p*
Pair 1	ghpre-ghpost	−35.534	−21.131	−8.139	23	<0.001	<0.001
Pair 2	intpre-intpost	−15.536	−4.630	−3.825	23	<0.001	<0.001
Pair 3	matpre-matpost	−8.976	5.309	−0.531	23	0.300	0.601
Pair 4	prefinger-postfinger	−3.879	0.254	−1.814	23	0.041	0.083

4. Key findings

Results were organized around each of four research questions: 1) How do Lamar undergraduate students use the SBD and biology content summaries? 2) How effective are the SBD and content summaries in increasing Lamar undergraduate students' ASL bioscience vocabulary and bioscience content knowledge? 3) How effective are the videos in increasing Lamar undergraduate ASL students' capacity to fingerspell terms and interpret typical undergraduate bioscience lecture material accurately and fluently? 4) What additions and/or changes would make the materials more effective?

4.1. Key findings for research question 1: How do Lamar undergraduate students use the SBD and biology content summaries?

Observations and survey responses show that participants used the SBD, to look up terms and definitions in ASL and English; see words signed; view illustrations;

learn new signs; and learn more about science. Most participants used the SBD to learn new signs and to learn the meaning of a term either because they did not know it or to help them review their knowledge of an aspect of biology content. They were generally satisfied with the information that was available for each term and with the accuracy of the signs. All participants found that use of the dictionary made learning science terms and definitions easier. In general, they read the content summaries and found them interesting.

4.2. Key findings for research question 2: How effective are the SBD and content summaries in increasing Lamar undergraduate students' ASL bioscience vocabulary and bioscience content knowledge?

As shown in **Tables 6** and **7**, participants' knowledge of STEM vocabulary was increased as evidenced by their ability to sign the terms following use of the SBD ($t(23) = 8.139$, $p = 0.001$; mean pretest = 8.229 and mean post-test = 36.562). However, participants' use of the SBD definitions and reading of the content summaries as evidenced by their ability to match terms and their definitions did not result in improvement in content knowledge ($t(23) = 0.532$, $p = 0.300$; mean pretest = 8.883 and mean post-test = 8.771). Therefore, vocabulary increased with use of the SBD but the content summaries did not lead to a significant increase.

4.3. Key findings for research question 3: How effective are the videos in increasing Lamar undergraduate ASL students' capacity to fingerspell terms and to interpret typical undergraduate bioscience lecture material accurately and fluently?

As also shown in the tables above, participants' ability to interpret typical biology lecture material was improved after learning the SBD vocabulary ($t(23) = 3.825$, $p = 0.001$; mean pretest = 2.415 and mean posttest = 12.500). After watching the videos of the fingerspelling principles and working with the research team on applying those principles their fingerspelling scores significantly improved ($t(23) = 1.814$, $p = 0.041$; mean pretest = 9.833 and mean posttest = 11.645).

4.4. Key findings for research question 4: What additions and/or changes would make the materials more effective?

Participant's responses to the participant survey indicate that they were satisfied with the videos and welcomed the opportunity to improve their fingerspelling. They were generally satisfied with the information that was available for the SBD terms. Many expressed a preference for a human signer to an avatar as they found the avatar difficult to understand.

4.5. Summary and implications of key findings

Study of the SBD in combination with summaries of fundamental bioscience content show that when used in study sessions that the SBD appears to contribute to Lamar university's student interpreters having an increased ASL bioscience vocabulary and ability to sign bioscience terms. Use of the definitions and access to information about relevant bioscience content does not appear to contribute to them having an increased knowledge of the content presented in a typical undergraduate biology lecture. Study of videos explaining the principles of fingerspelling and the application of these principles to the fingerspelling of terms included in the SBD show that when used in study sessions, these new and original resources appear to contribute to Lamar's student interpreters having an improved ability to accurately and fluently fingerspell bioscience terms. They also show that this new knowledge appears to translate into them having an increased ability to interpret typical bioscience lecture material accurately and fluently.

4.6. Limitations and further research

The present study has some important limitations. The results of the study cannot be generalized to all interpreting students in the Lamar program or to interpreting students in other programs. A larger, more representative sample of Lamar's interpreting students is needed as well as from programs in other parts of the country to further study the benefits of use of the SBD in combination with fingerspelling videos in increasing student interpreters' knowledge of ASL bioscience vocabulary and ability to sign bioscience terms and typical biology lecture content fluently and accurately. Additionally, the present study focused on use of a version of the SBD that incorporated a signing avatar and content information in the form of definitions and summaries. Additional research is needed to evaluate use of an SBD that incorporates a human signer and does not include content information in the form of definitions for terms and content summaries. Only then will we begin to discover the true benefit that use of an SBD and fingerspelling videos add to the preparation of interpreting students.

5. Conclusion

Conducting a study of use of the SBD, content summaries, and fingerspelling videos enabled researchers to begin to see that these new and unique novel resources increase interpreting students' ASL bioscience vocabulary and signing ability and accuracy and fluency of their fingerspelling. It also enabled them to see that they did not increase their content knowledge. Although this study provided important information, additional studies at Lamar and other institutions that do not include the summaries and that incorporate a human signer are needed before its results can be generalized. This additional information will enable researchers to ascertain the full potential of the SBD. The SBD, fingerspelling videos, and content summaries are available free from https://signsci.terc.edu/video/SBD/IUSE/.

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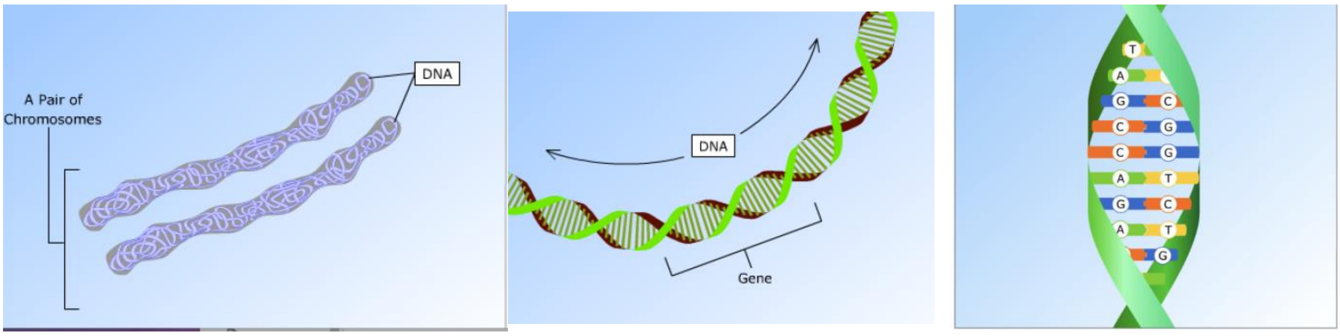
Appendix

An excerpt from the genes & heredity content summary

Genetic material

The cell is the basic structural unit of living things. It is the fundamental unit of which all organisms are composed. The cell is made up of specialized structures, each of which carries out one or more specific functions. One such cellular structure is the nucleus. The nucleus is a region inside the cell that is enclosed in a nuclear membrane and that contains the genetic material that carries specifications for reproduction of the cell, for building all the cellular components, and for coordinating cellular function. Chromosomes, genes, and DNA are important components of genetic material.

Chromosomes are discrete physical units that can be thought of as packages containing defined sets of genes, each of which is in a particular location on the chromosome. Humans have 23 pairs of chromosomes—or 46 chromosomes—in the nucleus of body cells. Each chromosome contains a defined set of hundreds or thousands of genes. The chromosome is composed of a long strand of deoxyribonucleic acid (DNA). If you observed DNA with a very powerful microscope, you might be able to see that its structure is a double helix and resembles a "twisted ladder." Each gene, specifying the information for a particular hereditary characteristic, is found in a specific region of the DNA. The array of genes contained in the chromosome run in a linear fashion, with one gene following another along the length of the DNA.



(a) **(b)** **(c)**

Figure A1. Genetic material, **(a)** chromosomes; **(b)** a section of a chromosome; **(c)** rungs of the DNA ladder.

Connecting the two sides of the DNA ladder are "rungs," each rung being made up of two units that, together, form a pair. A letter, which corresponds to the first letter of the units' names, identifies the individual units that make up the pair. The units are A (adenine), T (thymine), C (cytosine), G (guanine). The units pair according to a specific rule. For each rung of the double helix, the A unit always pairs with a T unit (or vice versa) and the C unit always pairs with a G unit (or vice versa). Therefore, each rung is made up of one of the pairs—either AT or TA or CG or GC. With other pair combinations, the ladder will fall apart. The ladder only "fits together" when the pairs AT, TA, CG, or GC are used.