Inferring Student Comprehension from Highlighting Patterns in Digital Textbooks: An Exploration in an Authentic Learning Platform

David Y.J. Kim, Adam Winchell, Andrew E. Waters
Phillip J. Grimaldi, Richard Baraniuk, Michael C. Mozer


University of Colorado **Boulder**


openstax™


RICE

Be Boulder.

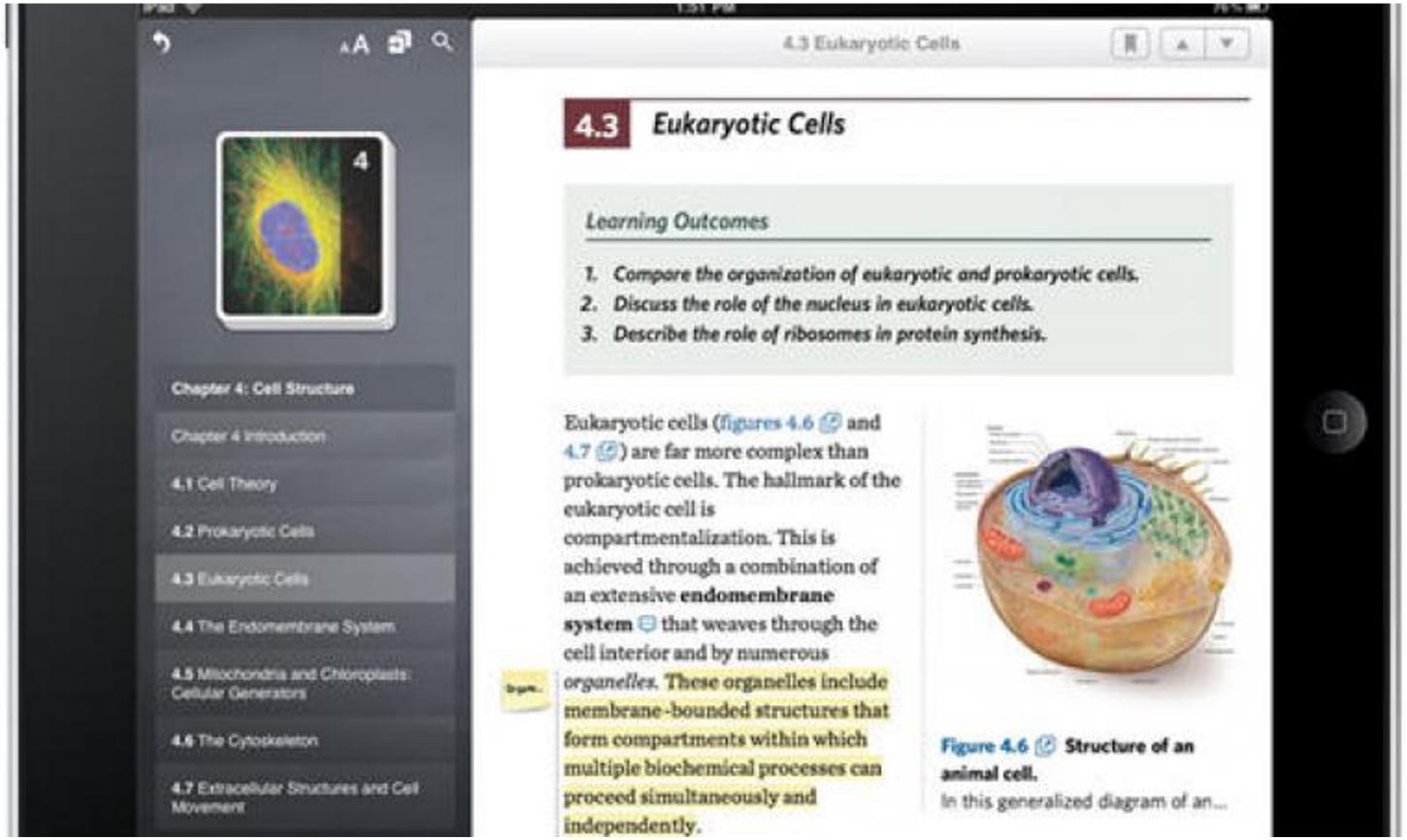
Motivation

Infer students' comprehension in digital textbooks by *implicit* measures

e.g., gaze, page view duration, scrolling rate

https://www.wan-ifra.org/articles/2013/08/19/more-people-are-reading-the-morning-paper-the-night-before

Our Focus



Most literature on highlighting asks whether it benefits student learning

Our focus is whether highlights can be used as a *data source* to *predict student comprehension and retention*

https://www.123rf.com/photo_36238093_education-concept-with-a-3d-rendering-of-related-words-and-knowledge-text-highlighted-with-a-yellow-.html

https://www.gpb.org/blogs/passion-for-learning/2012/10/03/the-digital-textbook-conundrum

Past Research

Winchell et al. (2020)

- 30 minute mechanical turk experiment
- Pattern of highlighting used to predict quiz performance

Waters et al. (2020)

- data collection in an authentic learning environment (Openstax)
- Did highlighting a sentence in the text improve memory for that sentence?

Past Research

Winchell et al. (2020)

- 30 minute mechanical turk experiment
- Pattern of highlighting used to predict quiz performance

Waters et al. (2020)

- Data collection in an authentic learning environment (Openstax)
- Did highlighting a sentence in the text improve memory for that sentence?

Our goal

- Use the pattern of highlighting to predict quiz score in an authentic digital learning environment

Data set

- Data is collected from Openstax Tutor over two semesters in 2018
  - Three introductory textbooks: Biology, Physics, and Sociology
- Each textbook is divided into *chapters* which can be further subdivided into *sections*.
  - Sections are about two pages long
  - Sections will be our unit of analysis
- Associated with each section is a set of questions that students answer.
- We obtain a *quiz score* for each student for each section, which is the student's average accuracy on the set of questions.

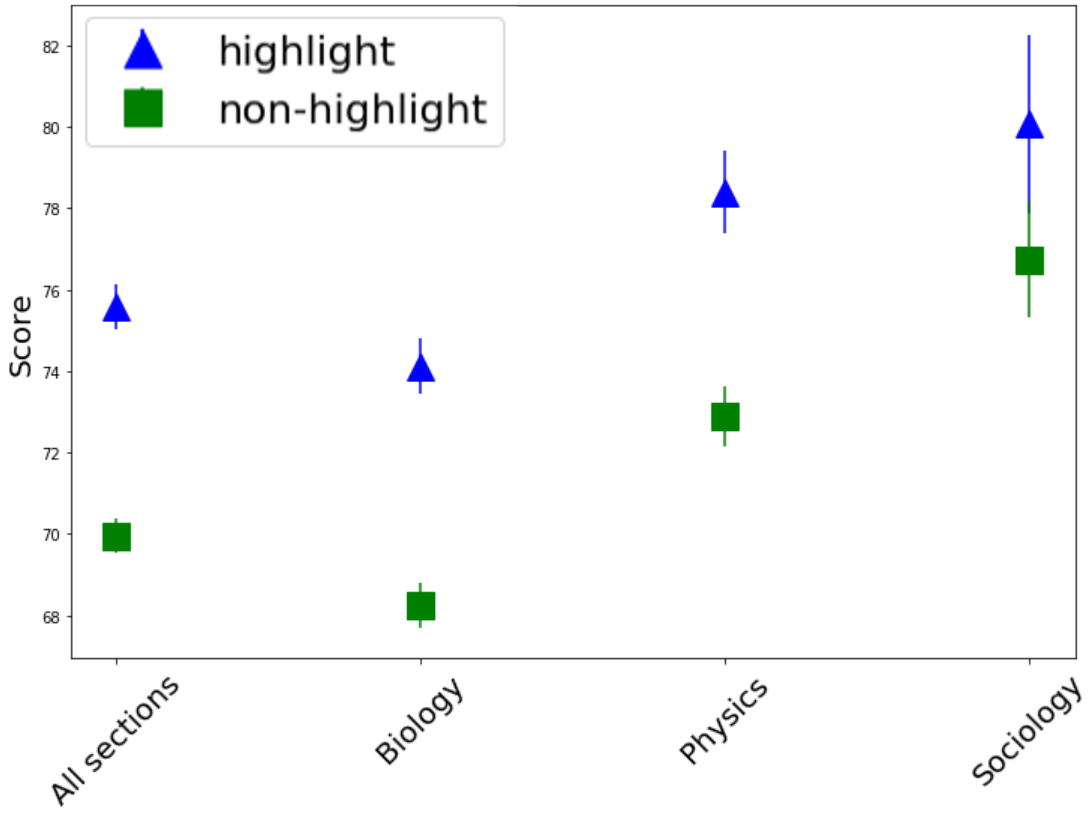
Data set summary statistics

	Biology	Physics	Sociology
Students	1,946	2,421	484
Sections	608	435	114
Sessions (Student-Sections)	185280	242902	51697
Max highlights per student	3038	1079	310
Mean highlights per section	4.2 (3.6)	0.9 (1.4)	1.2 (0.11)

- Surprising observation: relatively few highlights

Q. Does highlighting improve quiz performance?

- Students score higher on sections they highlight than sections they do not highlighting
  - Within student comparison
- Not due to differences in difficulty of the material, as indicated by no correlation of difficulty and portion of people highlighting



Q. Can we predict scores from the specific pattern of highlighting?

The process of disinfection inactivates most microbes on the surface of a fomite by using antimicrobial chemicals or heat. Because some microbes remain, the disinfected item is not considered sterile. Ideally, disinfectants should be fast acting, stable, easy to prepare, inexpensive, and easy to use. An example of a natural disinfectant is vinegar; its acidity kills most microbes. Chemical disinfectants, such as chlorine bleach or products containing chlorine, are used to clean nonliving surfaces such as laboratory benches, clinical surfaces, and bathroom sinks. Typical disinfection does not lead to sterilization because endospores tend to survive even when all vegetative cells have been killed.

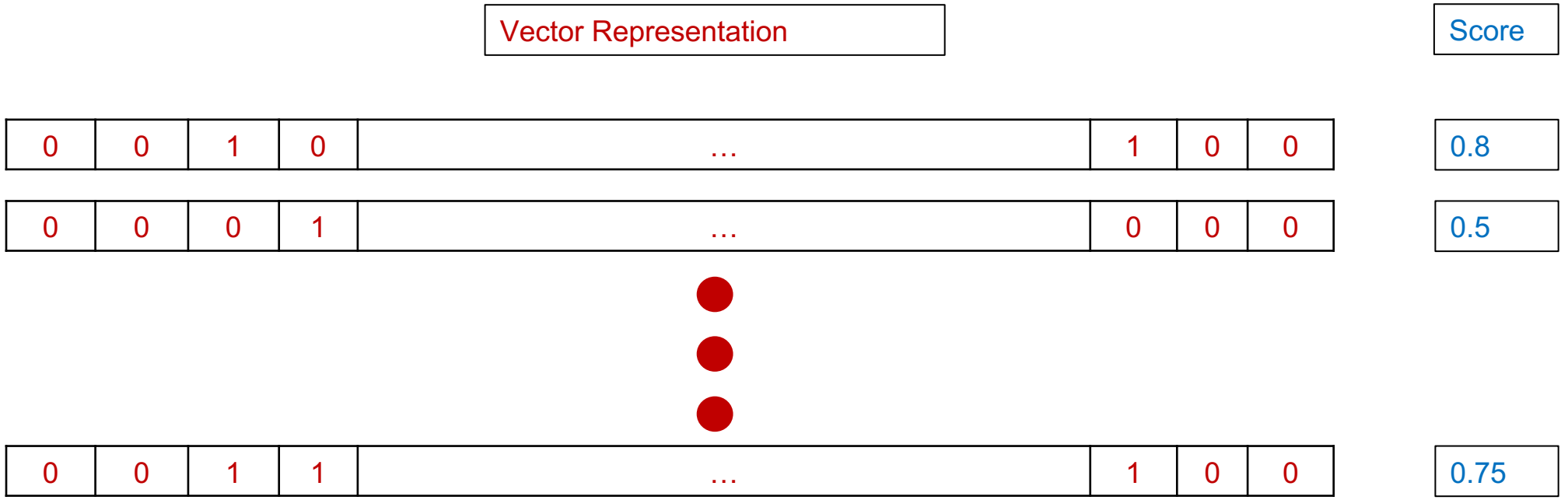
The process of disinfection inactivates most microbes on the surface of a fomite by using antimicrobial chemicals or heat. Because some microbes remain, the disinfected item is not considered sterile. Ideally, disinfectants should be fast acting, stable, easy to prepare, inexpensive, and easy to use. An example of a natural disinfectant is vinegar; its acidity kills most microbes. Chemical disinfectants, such as chlorine bleach or products containing chlorine, are used to clean nonliving surfaces such as laboratory benches, clinical surfaces, and bathroom sinks. Typical disinfection does not lead to sterilization because endospores tend to survive even when all vegetative cells have been killed.

The process of disinfection inactivates most microbes on the surface of a fomite by using antimicrobial chemicals or heat. Because some microbes remain, the disinfected item is not considered sterile. Ideally, disinfectants should be fast acting, stable, easy to prepare, inexpensive, and easy to use. An example of a natural disinfectant is vinegar; its acidity kills most microbes. Chemical disinfectants, such as chlorine bleach or products containing chlorine, are used to clean nonliving surfaces such as laboratory benches, clinical surfaces, and bathroom sinks. Typical disinfection does not lead to sterilization because endospores tend to survive even when all vegetative cells have been killed.

Procedure

- Selected 28 sections of Biology text
  - Minimum of 30 student highlighters
  - Maximum of 143 student highlighters
- Modeled each section independently with linear ridge regression
  - Regressor = representation of student highlights coded as a vector
  - Regressand = quiz score
- Ten fold cross validation
- We report fraction of quiz-score variance explained by the model on the hold-out set, averaged over the ten folds.

Regression Model



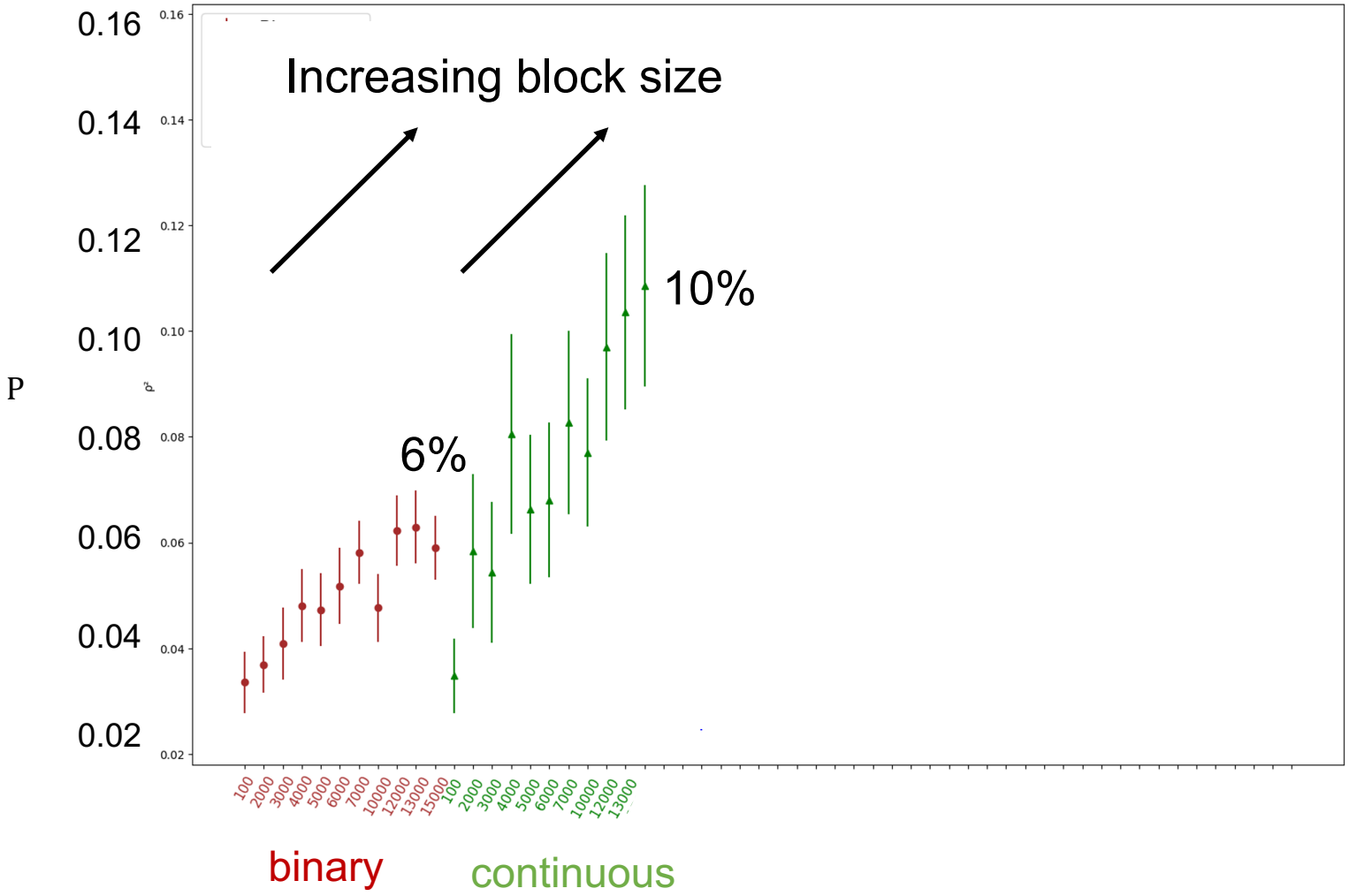
$$\hat{y}_i = \omega \boldsymbol{x}_i \qquad \omega = \operatorname{argmin}_w \|\boldsymbol{y} - \boldsymbol{X}w\|^2 + \lambda\|w\|^2$$

Character-block representation

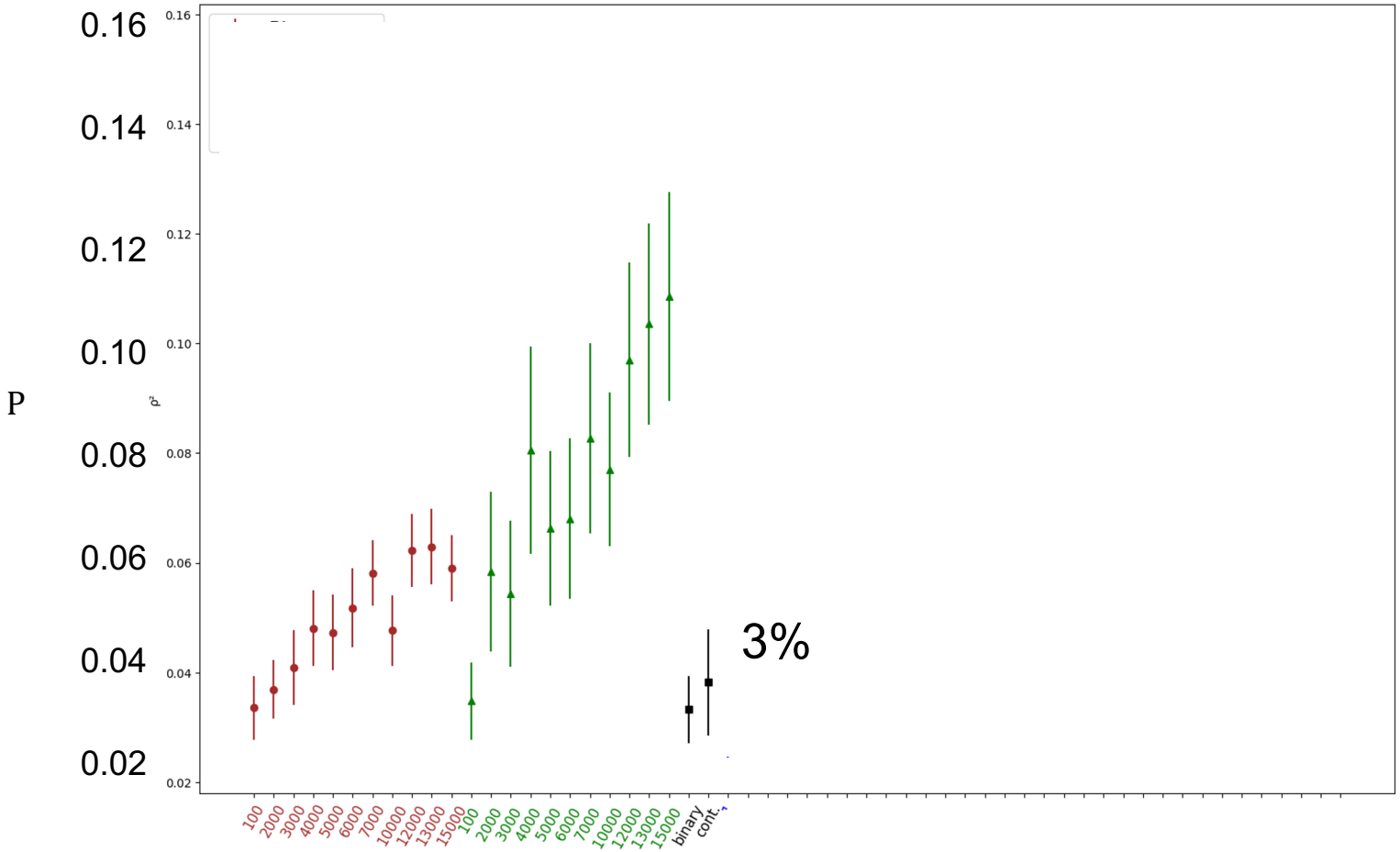
On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology. Escherichia coli (E. coli) bacteria, in this scanning electron micrograph, are normal residents of our digestive tracts that aid in absorbing vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. The Process of Science Biology is a science, but what exactly is science ? What does the study of biology share with other scientific disciplines? We can define science (from the Latin scientia, meaning “knowledge”) as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that applying scientific method plays a major role in science. The scientific method is a method of research with defined steps that include

- Blocked the text by number of characters, with blocks ranging in size from 100 to 15000 characters.
- One feature per block
- Binary representation: was any character in the block highlighted?
- Continuous representation: what fraction of characters in a block were highlighted?

Character-block representation



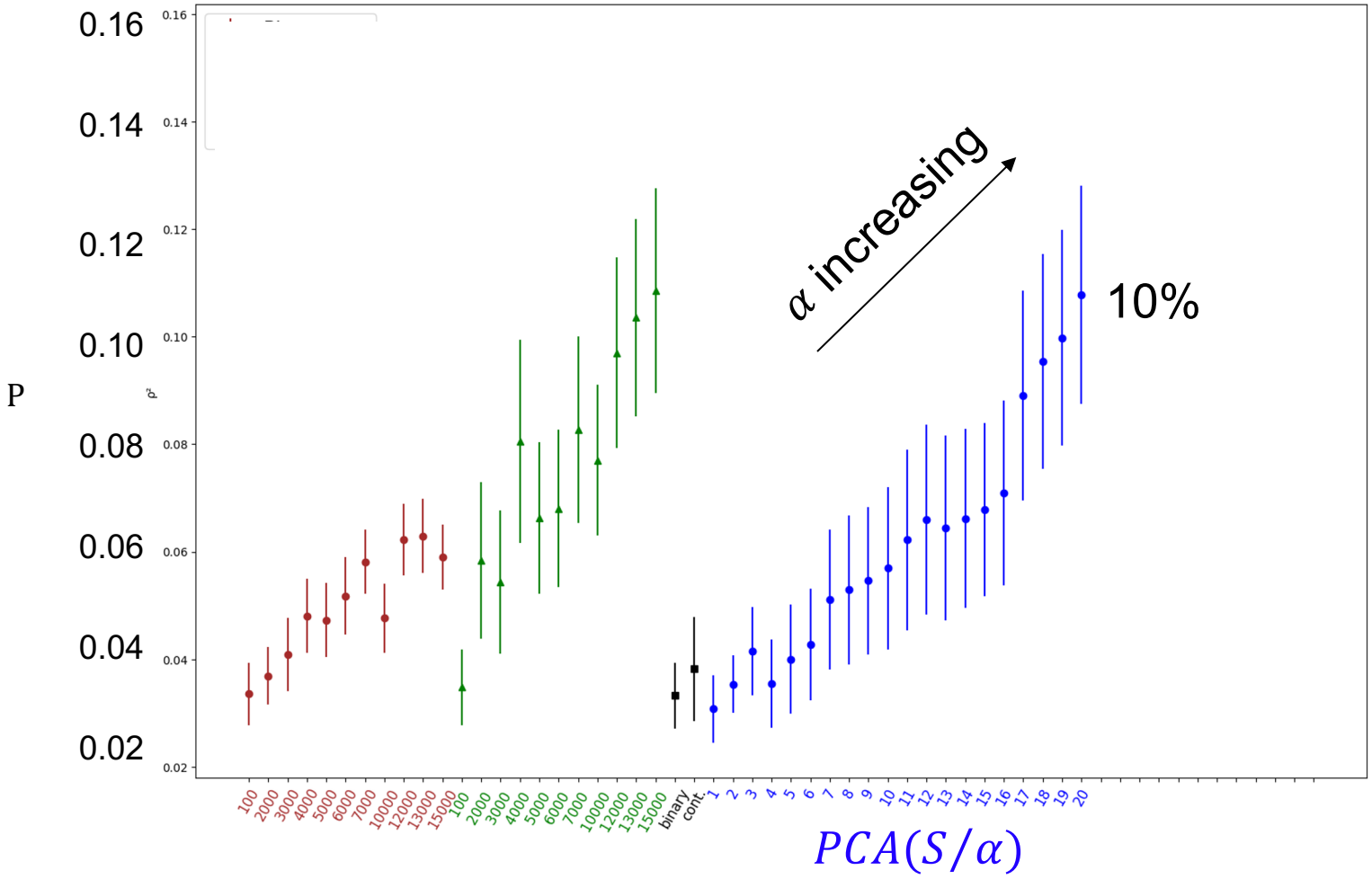
Sentence representation



Logistic $PCA(S/\alpha)$ representation

- For a section with *n* words, encode an *n*-dimensional vector indicating whether each word is highlighted
- Perform logistic principal components analysis to obtain *n* component vectors
- Select the top S/α components for the highlighting representation
  - S is the number of students in training set
  - α is a constant we select to vary size of representation

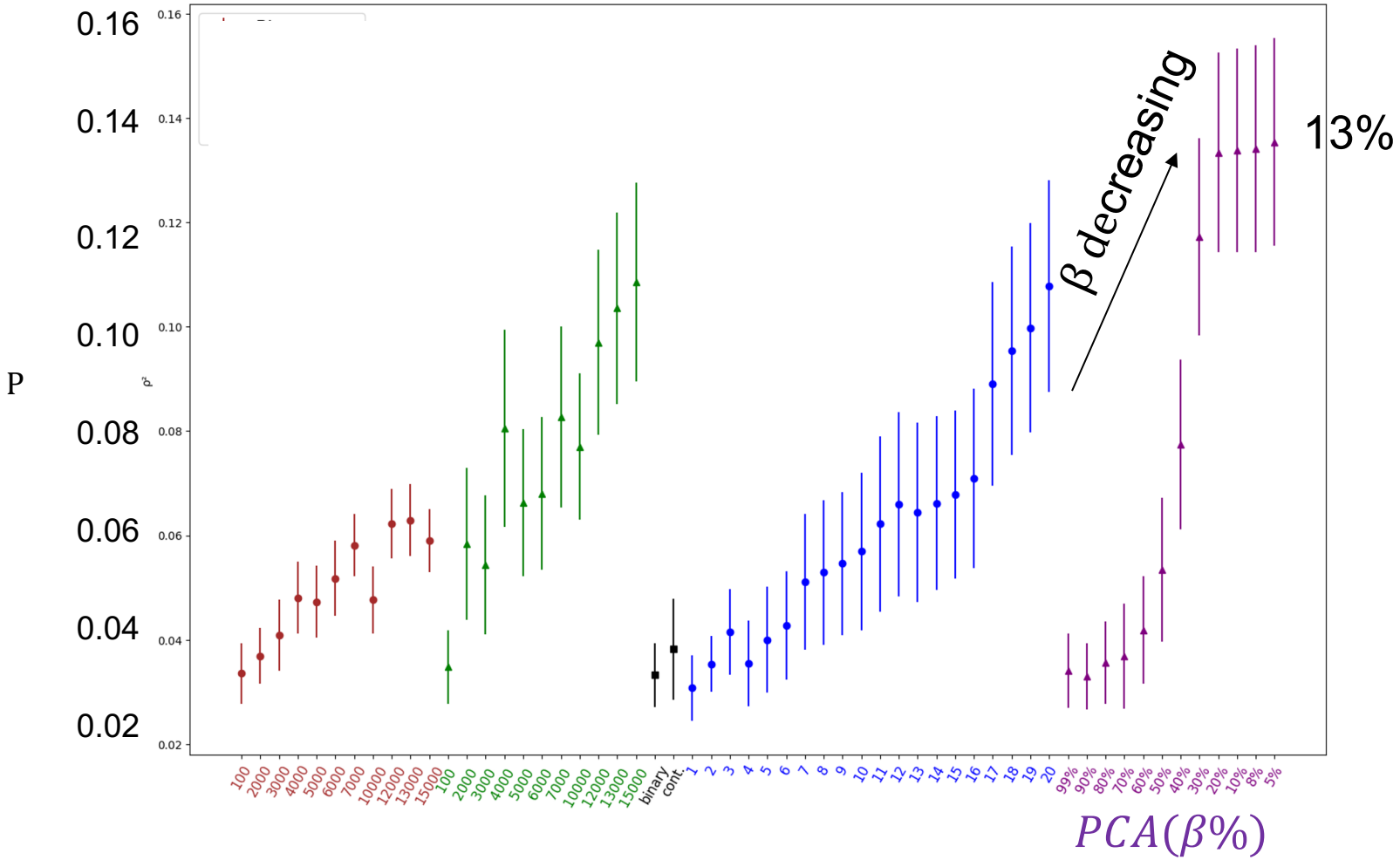
Logistic $PCA(S/\alpha)$ representation

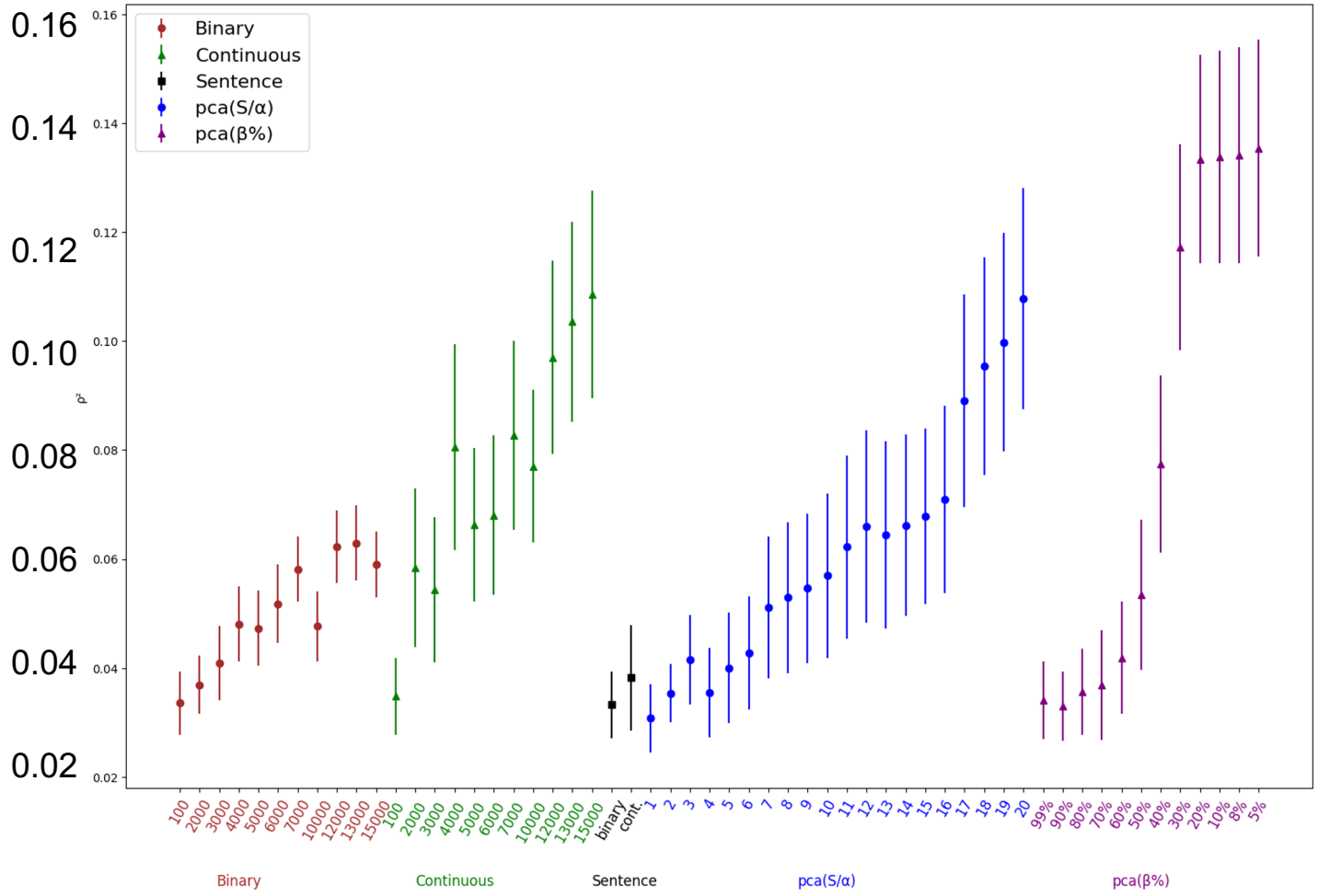


Logistic $PCA(\beta\%)$ representation

- Instead of choosing number of components based on data set size, express selection in terms of the fraction of components retained
- Select the top $\beta\%$ of components for the highlighting representation
  - E.g., if section has 1000 words and β=10% then use 100 components

Logistic $PCA(\beta\%)$ representation





P

We expected to see a trade off between

- *granularity of the representation*, which can capture subtle differences in highlighting,
- *fewer parameters*, which can prevent overfitting.

PCA(10%) word associations

On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology. Escherichia coli (E. coli) bacteria, in this scanning electron micrograph, are normal residents of our digestive tracts that aid in absorbing vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. The Process of Science Biology is a science, but what exactly is science ? What does the study of biology share with other scientific disciplines? We can define science (from the Latin scientia, meaning “knowledge”) as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that applying scientific method plays a major role in science. The scientific method is a method of research with defined steps that include experiments and careful observation. We will examine scientific method steps in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A hypothesis is a suggested explanation for an event, which one can test. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, psychology, and geology, the scientific method becomes less applicable as repeating experiments becomes more difficult. These areas of study are still sciences, however. Consider archaeology—even though one can not perform repeatable experiments, hypotheses may still be supported. For instance, an archaeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. He or she could make further hypotheses about various characteristics of this culture, which could be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A theory is a tested and confirmed explanation for observations or phenomena.

Student scoring 100%

On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology. Escherichia coli (E. coli) bacteria, in this scanning electron micrograph, are normal residents of our digestive tracts that aid in absorbing vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. The Process of Science Biology is a science, but what exactly is science ? What does the study of biology share with other scientific disciplines? We can define science (from the Latin scientia, meaning "knowledge") as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that applying scientific method plays a major role in science. The scientific method is a method of research with defined steps that include experiments and careful observation. We will examine scientific method steps in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A hypothesis is a suggested explanation for an event, which one can test. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, psychology, and geology, the scientific method becomes less applicable as repeating experiments becomes more difficult. These areas of study are still sciences, however. Consider archaeology—even though one can not perform repeatable experiments, hypotheses may still be supported. For instance, an archaeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. He or she could make further hypotheses about various characteristics of this culture, which could be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A theory is a tested and confirmed explanation for observations or phenomena.

Student scoring 54%

On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology. Escherichia coli (E. coli) bacteria, in this scanning electron micrograph, are normal residents of our digestive tracts that aid in absorbing vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. The Process of Science Biology is a science, but what exactly is science ? What does the study of biology share with other scientific disciplines? We can define science (from the Latin scientia, meaning “knowledge”) as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that applying scientific method plays a major role in science. The scientific method is a method of research with defined steps that include experiments and careful observation. We will examine scientific method steps in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A hypothesis is a suggested explanation for an event, which one can test. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, psychology, and geology, the scientific method becomes less applicable as repeating experiments becomes more difficult. These areas of study are still sciences, however. Consider archaeology—even though one can not perform repeatable experiments, hypotheses may still be supported. For instance, an archaeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. He or she could make further hypotheses about various characteristics of this culture, which could be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A theory is a tested and confirmed explanation for observations or phenomena.

Discussion

- We found that highlighting patterns can explain about 13% of the variance in mean score (pca(β%), β<30%)
- Many factors can play into students' scores
  - E.g., interests, engagement, prior knowledge, retention period
- Considering these many factors, the predictive power that comes from using highlighting features is both statistically and educationally significant.
- Although our data set is large, we did not have a lot of students who highlighted a given section. Hopefully, as we obtain more data from students who highlight, the models will make stronger predictions.

Future Research

- We plan to explore alternative representations of highlighting whose dimensionality depends both on the amount of data (S) as well as the number of words in the section.
- Incorporate other aspects of the highlights (e.g., their timing, whether highlights were deleted)
- Consider individual differences among students (e.g., IRT models)
- Incorporate other data sources, in particular scrolling patterns

Questions?