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Session 3A: Data Science and Dissemination

Tracking Cross-State Achievement Gap Trajectory in NAEP Assessments with Dynamic Time Warping Methods

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1 Overview

- National Report Card
- Cross-State Achievement Gap Trajectories

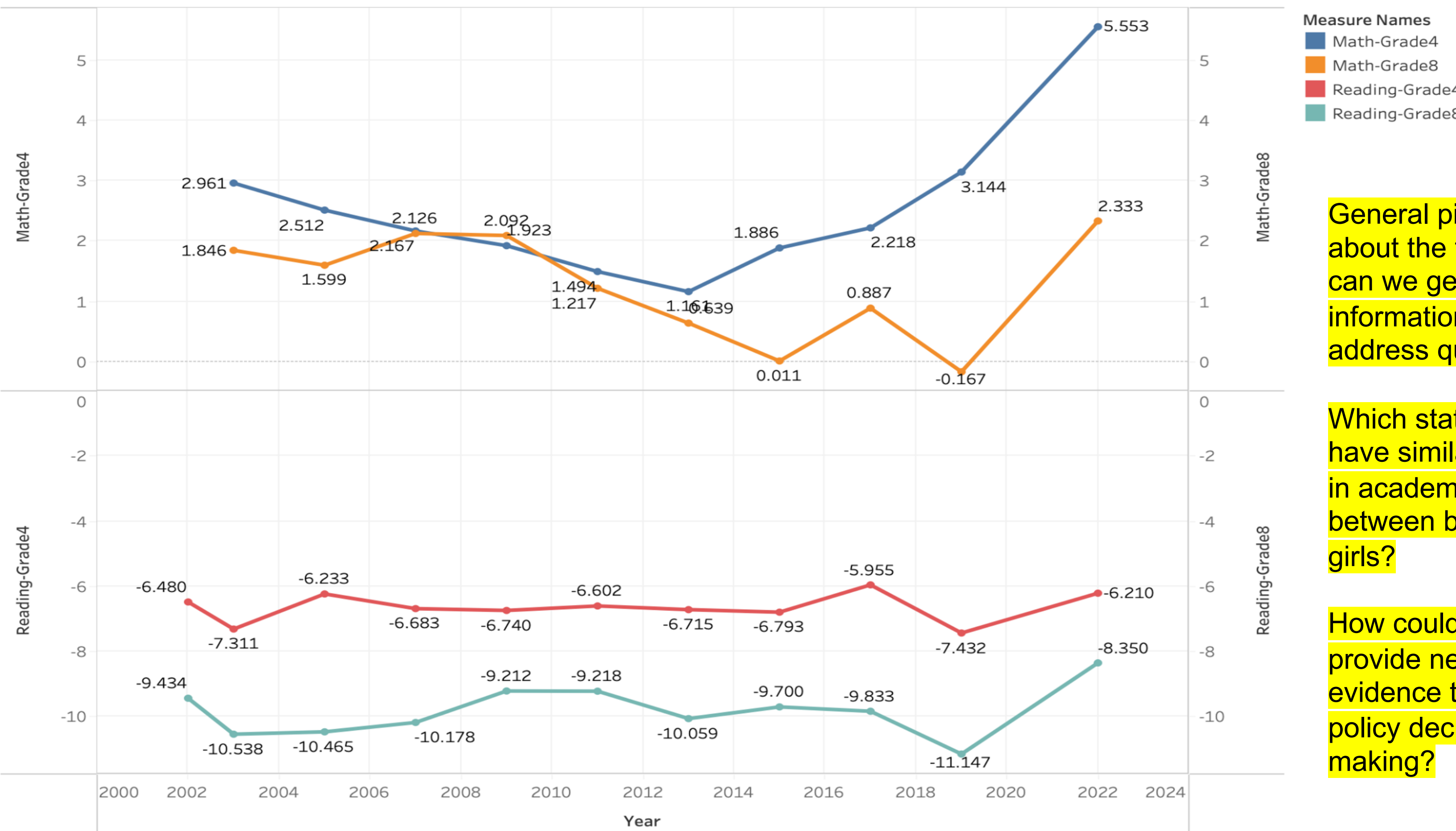
National Report Card

NAEP
NATIONAL ASSESSMENT OF EDUCATIONAL PROGRESS

- Educational assessment plays **a crucial role** in uncovering learning disparities and shaping data-informed education policy (NCES, 2023).
- The **National Assessment of Educational Progress (NAEP)** is a nationally representative and continuing assessment of what America's students know and can do in various subjects, generally in Grade 4, 8, 12.
- Academic performance by different demographic groups, such as achievement gap between boys and girls, has aroused great attention since the start of NAEP.
- Within the past two decades, **over 42,900 journal papers** were published on the topic with "NAEP and demographic groups".
- However, **very few research** showed a **comprehensive picture through the NAEP development history and identify trajectory changes across states.**

Overview of Academic Gap by Years and Subjects

National Reading VS. Math Gender Gap



The trends of Math-Grade4, Math-Grade8, Reading-Grade4 and Reading-Grade8 for Year. Color shows details about Math-Grade4, Math-Grade8, Reading-Grade4 and Reading-Grade8.

General picture about the trajectory, can we get granular information to address questions:

Which state(s) may have similar patterns in academic gap between boys and girls?

How could we provide new evidence to support policy decision making?

Objectives

- Track cross-state achievement gap trajectories in NAEP Assessments
- Identify trajectory patterns by boys and girls across grades and subjects
- Provide new evidence to policy makers through data-driven approach

2 Methods

- Dynamic Time Warping Similarity Measurement
- Sequence Clustering

Data

- **Subjects:** Math and Reading across 50 states

- **Grades:** Grade 4 and Grade 8

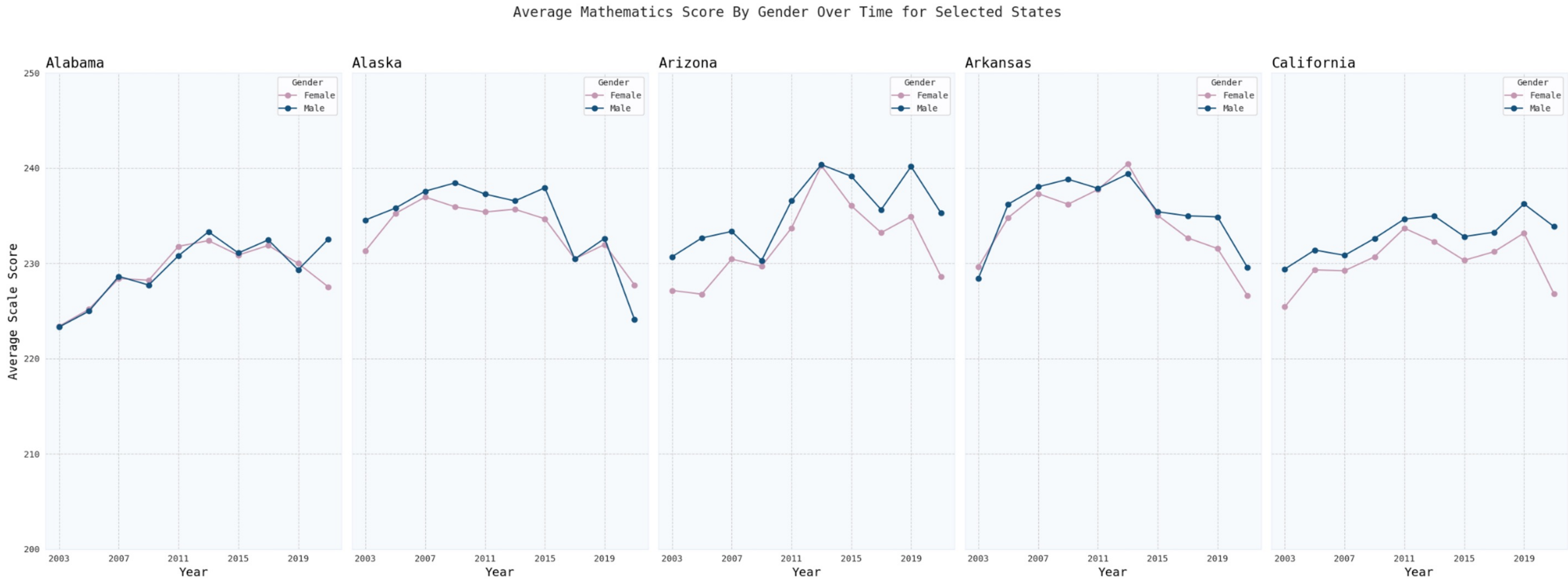
- **Years Covered:** 2002–2022

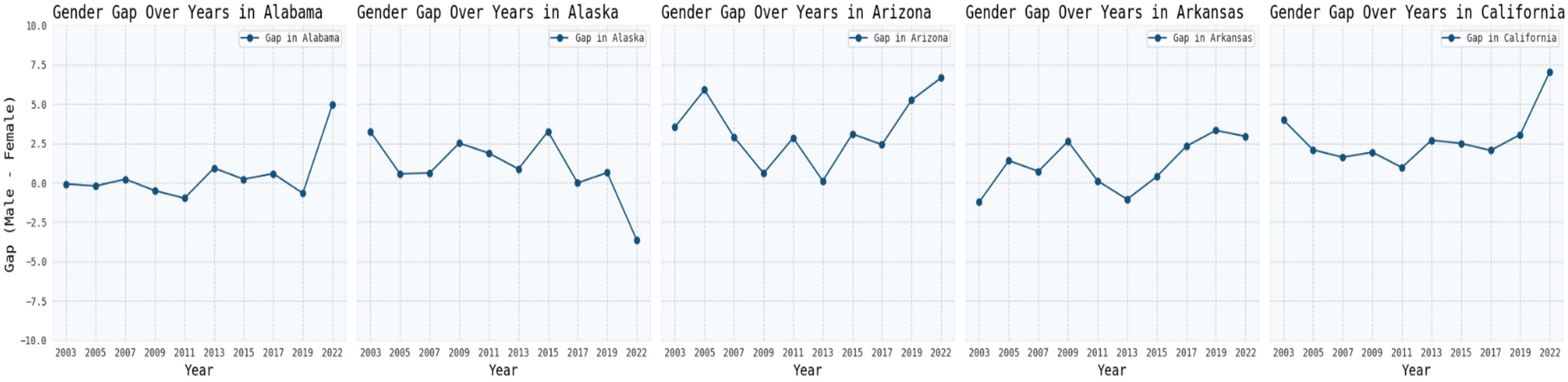
- **Gender gap:** $M_{male} - M_{female}$ per cycle per subject

- Sequence data analysis

NAEP NATIONAL ASSESSMENT OF EDUCATIONAL PROGRESS

Sequence Data by State (Grade 4 Math)

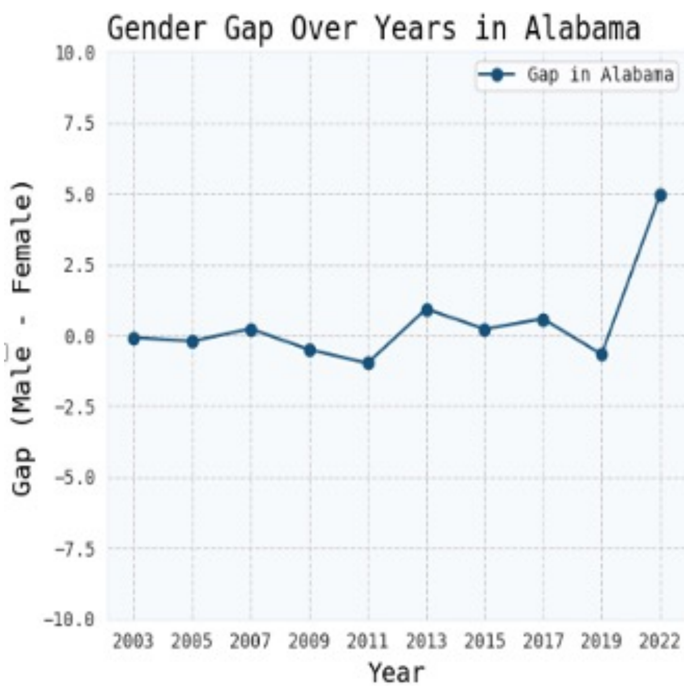




Sequence Data by State

Gender difference across years in Grade 4 Math

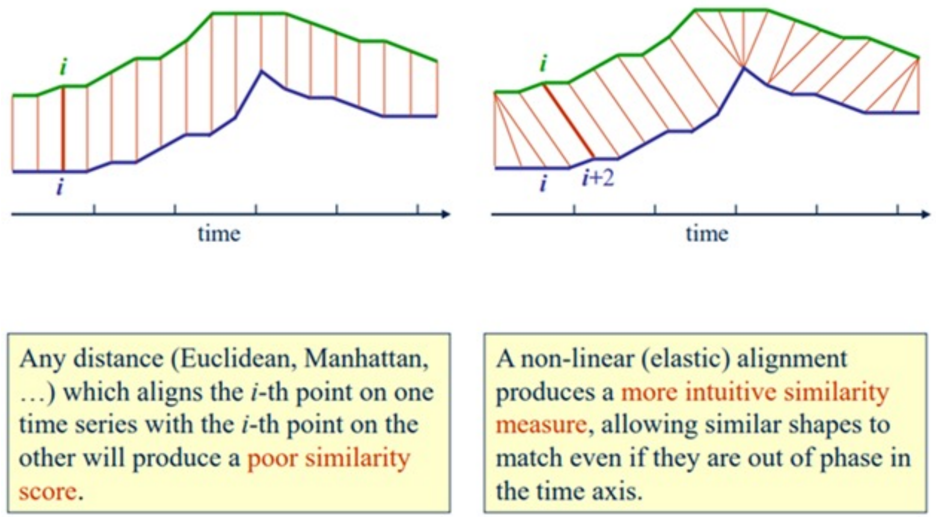
	2003	2005	2007	2009	2011	2013	2015	2017	2019	2022
Alabama	-0.08	-0.21	0.23	-0.51	-0.98	0.93	0.22	0.58	-0.67	4.96
Alaska	3.23	0.56	0.62	2.52	1.87	0.87	3.26	-0.01	0.64	-3.64



Dynamic Time Warping (DTW) (He et al., 2023)

- Dynamic time warping (Sakoe & Chiba, 1978) is a distance measure that searches the optimal warping path between two series.

- Given sequences $X = \{x_1, x_2, \ldots, x_n\}$ and $Y = \{y_1, y_2, \ldots, y_m\}$ with the same or different lengths, a warping path W is an alignment between X and Y, involving one-to-many mappings for each pair of elements.



He, Q., Borgonovi, F., Suárez-Álvarez, J. (2023). Clustering Sequential Navigation Patterns in Multiple-Source Reading Tasks with Dynamic Time Warping Method. *Journal of Computer-Assisted Learning, 39*(3), 719-736.

Dynamic Time Warping Algorithm

- The initial step of DTW algorithm is defined as:

$$DTW(i,j) = \begin{cases} \infty & if\ (i = 0\ or\ j = 0)\ and\ i \neq j \\ 0 & if\ i = j = 0 \end{cases}$$

- The recursive function of DTW is defined as

$$DTW(i,j) = min \begin{cases} DTW(i-1,j) + w_h C(i,j) \\ DTW(i,j-1) + w_v C(i,j) \\ DTW(i-1,j-1) + w_d C(i,j) \end{cases}$$

where (w_h, w_v, w_d) are weights for the horizontal, vertical and diagonal directions, respectively. $DTW(i,j)$ denotes the distance or cost between two sub-sequences $\{x_1, x_2, \ldots, x_i\}$ and $\{y_1, y_2, \ldots, j\}$, and $DTW(N,M)$ indicates the total cost of the optimal warping path.

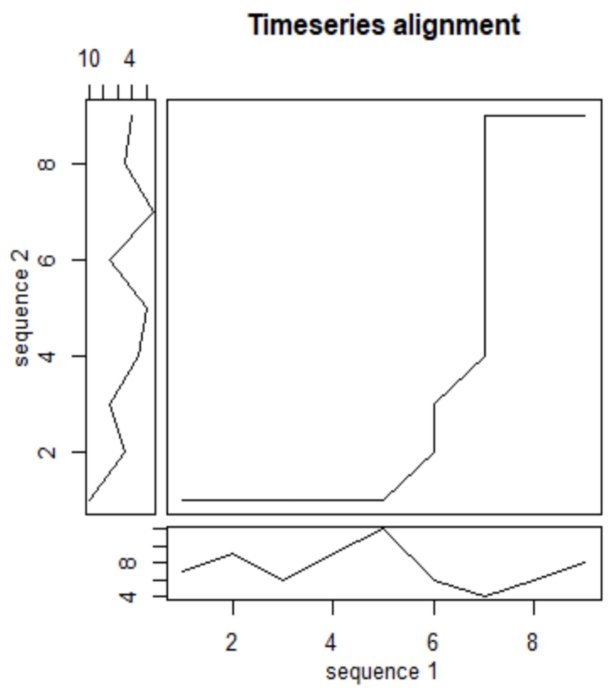
A	**5**	10	6	3	1	2	4	3
	4	6	3	1	0	1	3	3
	3	3	1	0	1	1	2	4
	2	1	0	1	3	4	4	7
	1	0	1	3	6	8	9	13
		1	**2**	**3**	**4**	**3**	**2**	**5**
		B						

$A_i = \{1, 2, 3, 4, 5\}$
$B_j = \{1, 2, 3, 4, 3, 2, 5\}$
$$dtw(i,j) = |A_i - B_j| + \min(D[i-1, j-1], D[i-1, j], D[i, j-1])$$
$$= |5 - 2| + 3$$

Dynamic Time Warping Similarity

Dynamic Time Warping (DTW)

- A time-series alignment algorithm to measure similarity between sequences that may vary in time or speed.
- Useful when states drop from certain cycles, causing unequal sequence lengths.
- DTW constructs a cost matrix and finds the optimal warping path between two sequences.
- Only applicable to numeric sequences, so categorical data needs to be numerically encoded.



Sequence Clustering

Sequence Clustering

- Performed on the DTW distance matrix.

- Uses partition-based clustering (K-medoids), where clusters are formed based on minimizing within-cluster DTW distances.
  - Starts by randomly selecting representative points (medoids).
  - Assigns other sequences to the nearest medoid.
  - Repeats until cluster centers stabilize.

- **Cluster Validity Indices Used**
  - **Silhouette Index:** Measures how similar an object is to its cluster vs. others.
  - **Dunn Index:** High inter-cluster, low intra-cluster distances preferred.
  - **Davies-Bouldin Index:** Measures cluster compactness and separation.

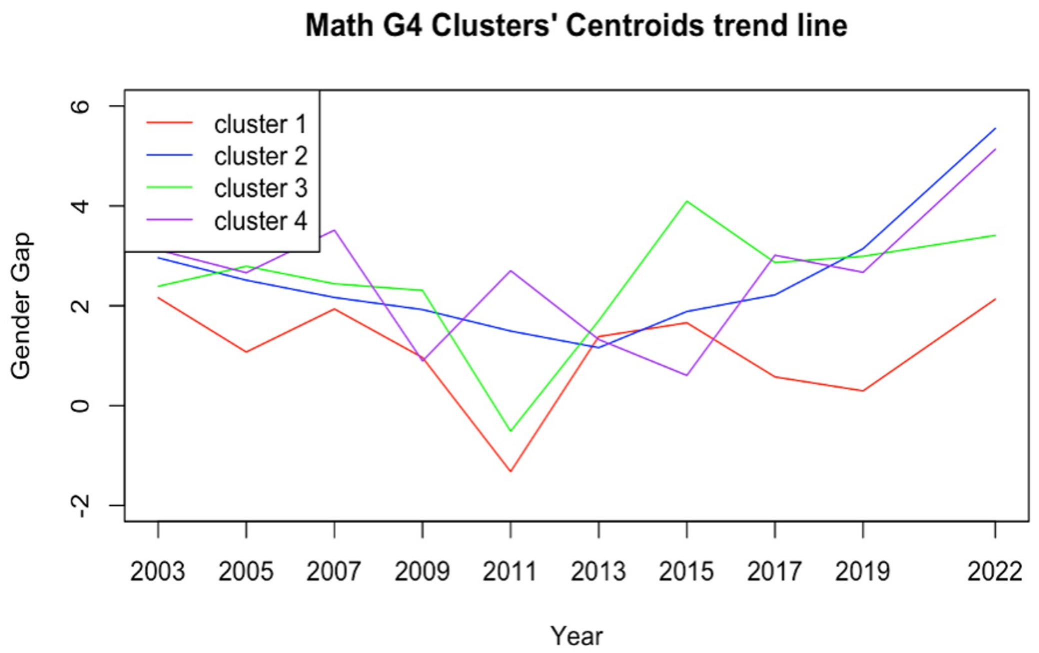
- Iterated values of K = 2 to 10, selected **4 clusters** as optimal

3 Results

- Trajectory patterns across states
- Achievement gap changes across grades and subjects

Trajectory Pattern Across States – Grade 4 Math

- **Cluster 1 (Red):** Significant drop in 2011 and 2015–2019, sharp increase post-2019.
- **Cluster 2 (Blue):** Relatively stable from 2003–2017, but steeply increase after 2017.
- **Cluster 3 (Green):** Similar shape as Cluster 1 but with not significantly impact by COVID.
- **Cluster 4 (Purple):** Up and down in big waves but steeply rises after 2019.



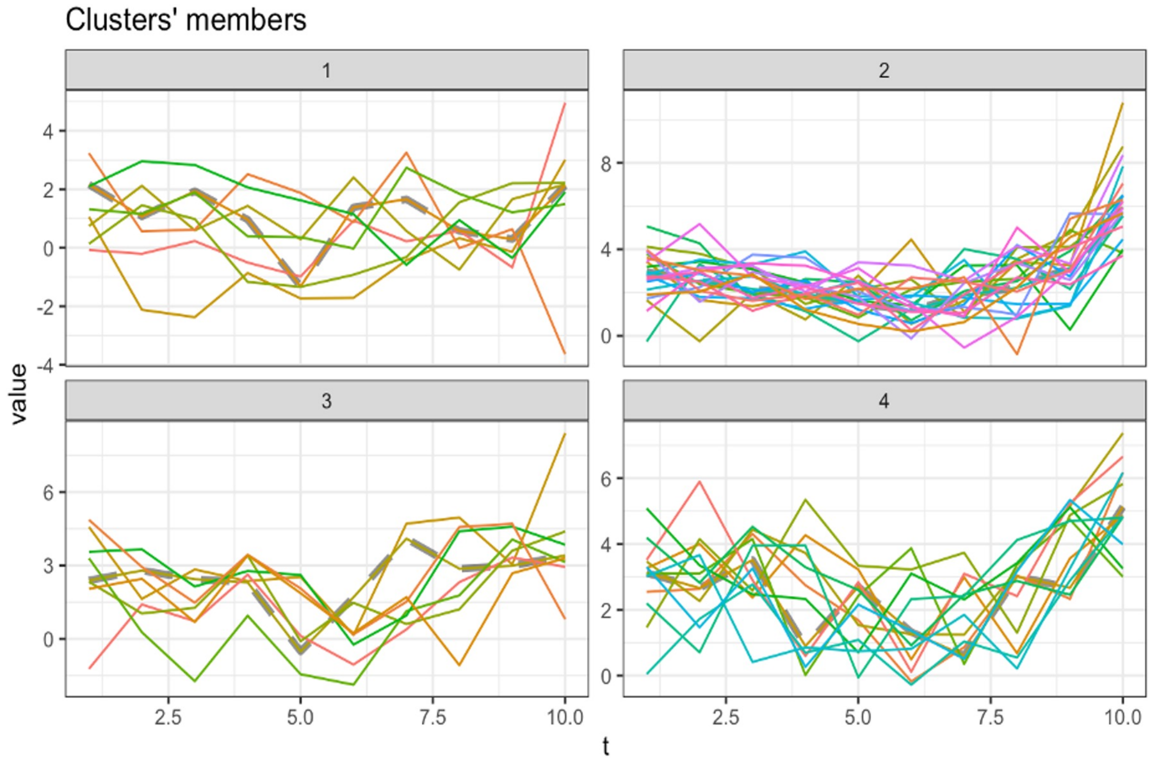
Trajectory Pattern Across States – Grade 4 Math

Cluster 1 : (8 States)
Alabama, Alaska, Georgia, Hawaii, Louisiana, Mississippi, North Carolina, West Virginia

Cluster 2 : (21 States)
California, Colorado, Florida, Idaho, Indiana, Iowa, Kansas, Kentucky, Michigan, Missouri, Nevada, New Jersey, New Mexico, New York, Ohio, Pennsylvania, Utah, Vermont, Virginia, Wisconsin, Wyoming

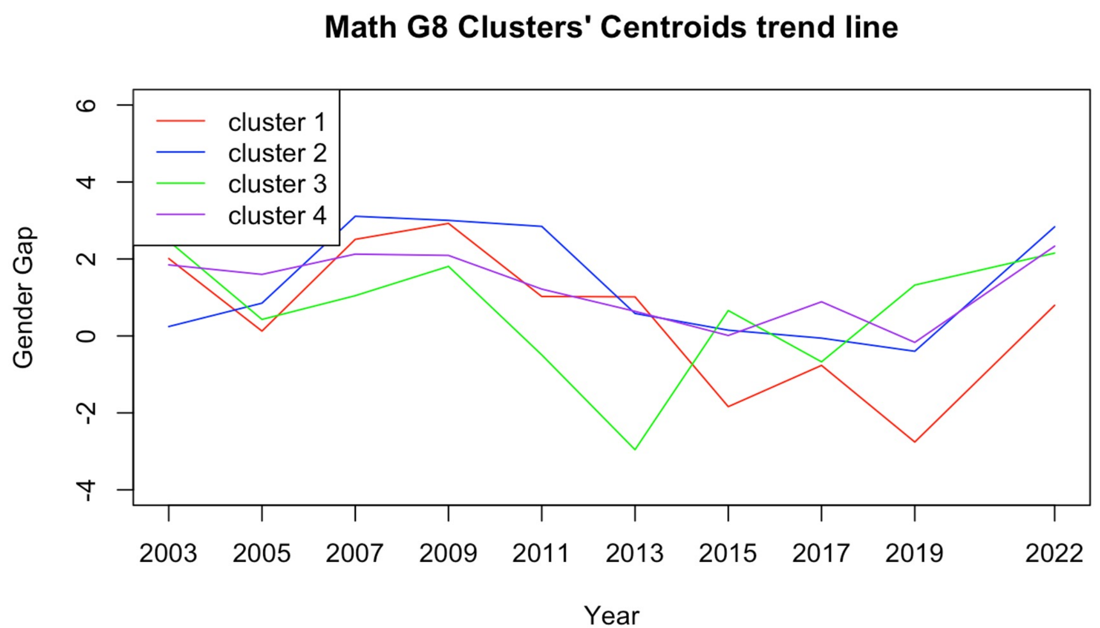
Cluster 3 : (8 States)
Arkansas, Connecticut, Delaware, Massachusetts, Oklahoma, Rhode Island, South Carolina, South Dakota"

Cluster 4 : (13 States)
Arizona, Illinois, Maine, Maryland, Minnesota, Montana, Nebraska, New Hampshire, North Dakota, Oregon, Tennessee, Texas, Washington



Trajectory Pattern Across States – Grade 8 Math

- **Cluster 1 (Red):** significantly dropped between 2015 and 2019, but sharply increased after 2019.
- **Cluster 2 (Blue):** Stable and a bit down between 2003 and 2017, sharply increased after 2019.
- **Cluster 3 (Green):** Gap dropped to the lowest value in 2013, and kept fast increasing afterwards.
- **Cluster 4 (Purple):** Stable and a small dropping trend until 2019, where a noticeable spike appeared after 2019.



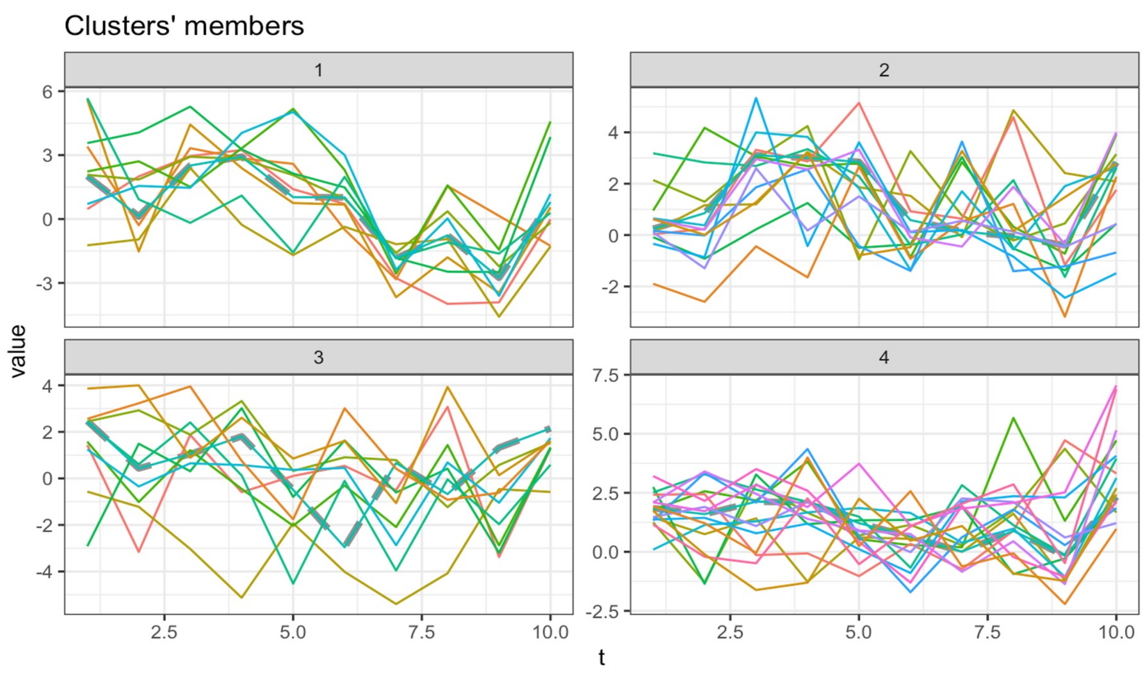
Trajectory Pattern Across States – Grade 8 Math

Cluster 1 : (10 States)
Kentucky, Maryland, Massachusetts, North Carolina, Ohio, Oregon, Pennsylvania, South Carolina, South Dakota, Wyoming

Cluster 2 : (14 States)
Arizona, Arkansas, Colorado, Kansas, Maine, Michigan, Montana, Nebraska, North Dakota, Oklahoma, Tennessee, Vermont, West Virginia, Wisconsin

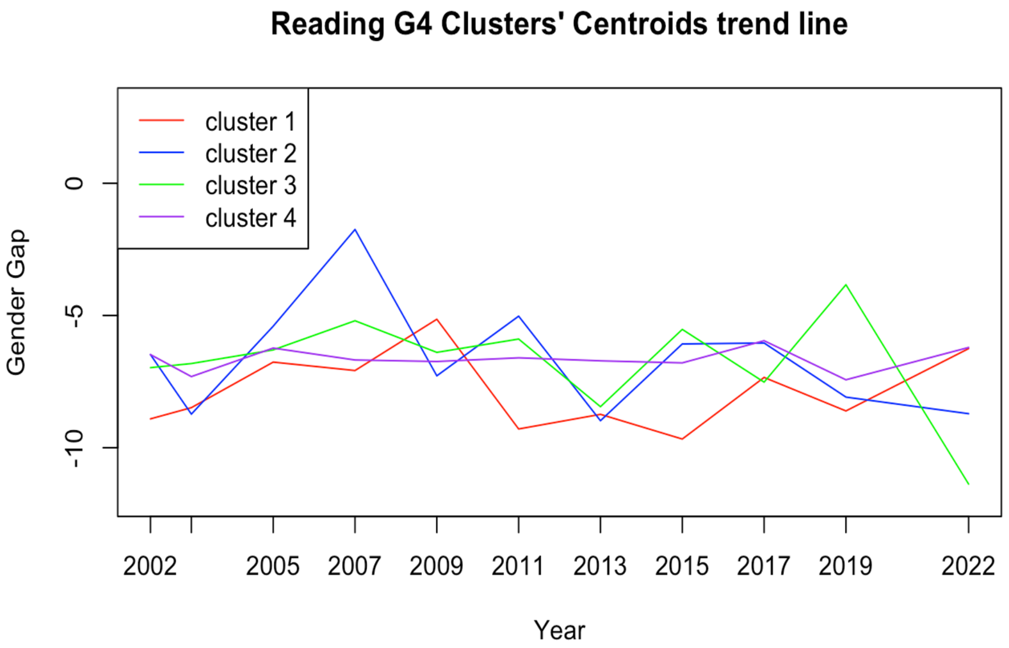
Cluster 3 : (10 States)
Alabama, Delaware, Florida, Hawaii, Indiana, Louisiana, Minnesota, Mississippi, New York, Rhode Island

Cluster 4 : (16 States)
Alaska, California, Connecticut, Georgia, Idaho, Illinois, Iowa, Missouri, Nevada, New Hampshire, New Jersey, New Mexico, Texas, Utah, Virginia, Washington



Trajectory Pattern Across States – Grade 4 Reading

- **Cluster 1 (Red)**: Consistently large gap (girls outperform over boys), gap slightly narrowed after 2019.
- **Cluster 2 (Blue)**: High peak around 2007 indicating the smallest gender gap, curve waves showing in the recent decade.
- **Cluster 3 (Green)**: Fairly stable until 2017, with a sharp spike in 2019 (with the smallest gender gap), followed by a sharp drop in 2022 after COVID.
- **Cluster 4 (Purple)**: Consistently stable with moderate gender gap across all years.



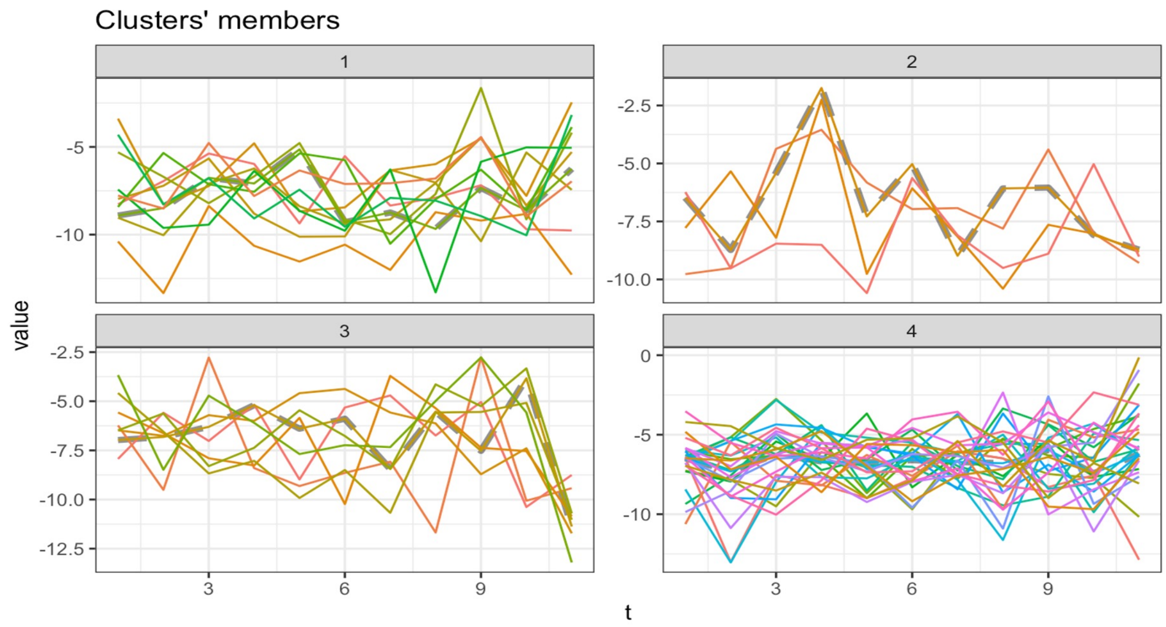
Trajectory Pattern Across States – Grade 4 Reading

Cluster 1 : (11 States)
Alabama, Florida, Hawaii, Indiana, Missouri, Oregon, Pennsylvania, South Carolina, Vermont, Washington, West Virginia

Cluster 2 : (4 States)
Arkansas, Montana, New Mexico, Wisconsin

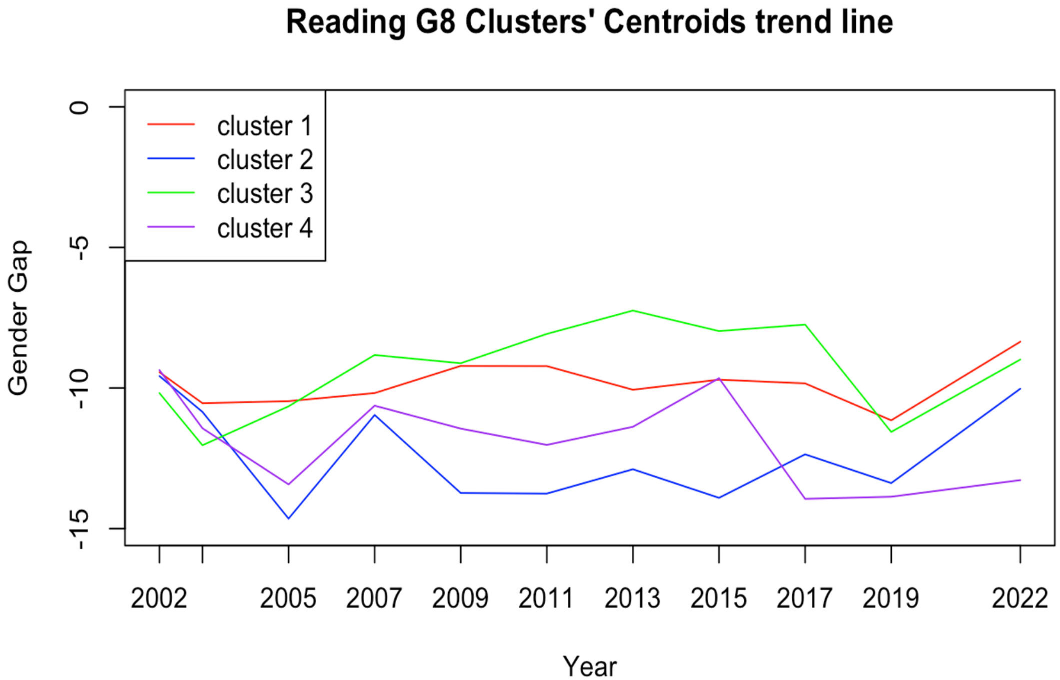
Cluster 3 : (8 States)
Idaho, Louisiana, Mississippi, New Jersey, Oklahoma, Rhode Island, South Dakota, Virginia

Cluster 4 : (27 States)
Alaska, Arizona, California, Colorado, Connecticut, Delaware, Georgia, Illinois, Iowa, Kansas, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, Nevada, New Hampshire, New York, North Carolina, North Dakota, Ohio, Tennessee, Texas, Utah, Wyoming



Trajectory Pattern Across States – Grade 8 Reading

- **Cluster 1 (Red)**: Consistently wide gender gap across years, with a slight narrowing in 2013–2017 and a small uptick after 2019.
- **Cluster 2 (Blue)**: The largest gender gap, esp. the lowest point at 2005, the gap slightly narrowed down after 2017.
- **Cluster 3 (Green)**: The narrowest gender gap among clusters between 2007 and 2015, a big drop in 2019, with a slight increasing trend (gap narrowing) in 2022.
- **Cluster 4 (Purple)**: Moderate fluctuations with a noticeable drop in 2017, relatively stable afterwards.



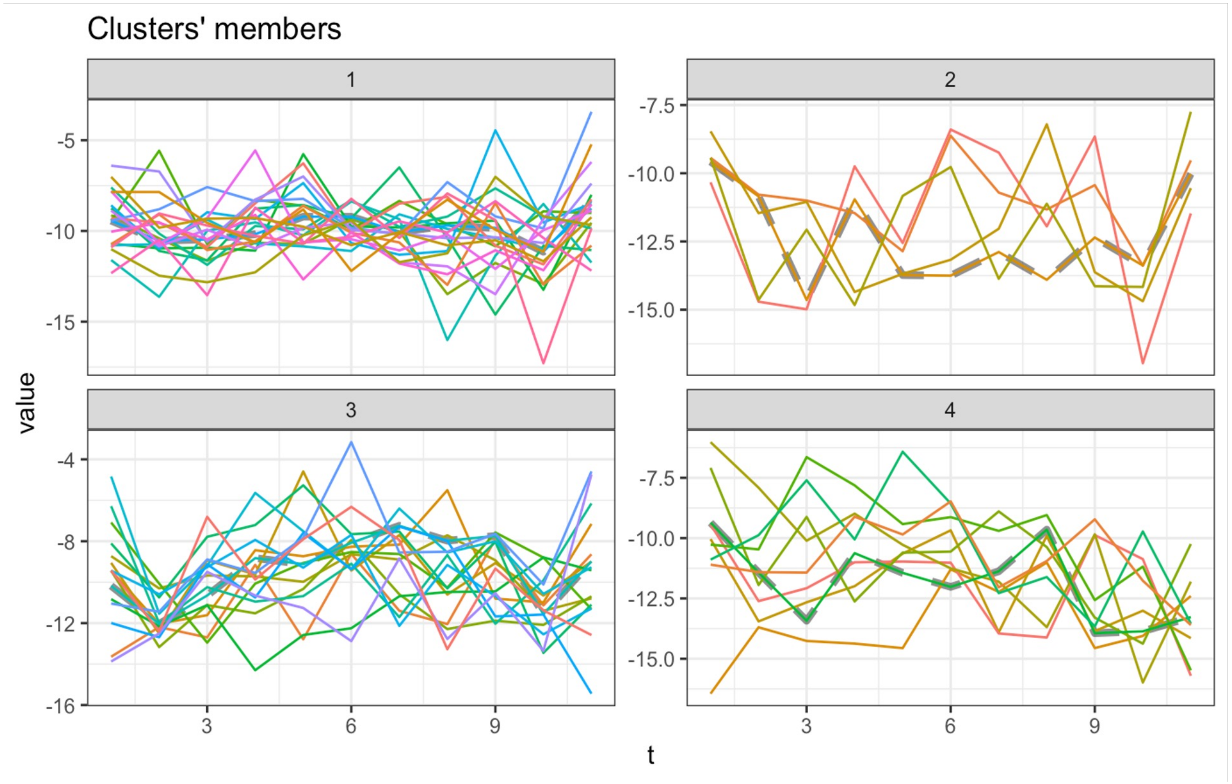
Trajectory Pattern Across States – Grade 8 Reading

Cluster 1 : (20 States)
Arizona, Arkansas, California, Delaware, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maryland, Michigan, Mississippi, New Jersey, Ohio, Oregon, Rhode Island, South Carolina, Utah, Virginia

Cluster 2 : (5 States)
Alabama, New Hampshire, North Carolina, West Virginia, Wisconsin

Cluster 3 : (16 States)
Colorado, Idaho, Iowa, Kansas, Massachusetts, Minnesota, Nebraska, Nevada, New Mexico, New York, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Washington

Cluster 4 : (9 States)
Alaska, Connecticut, Hawaii, Maine, Missouri, Montana, North Dakota, Vermont, Wyoming



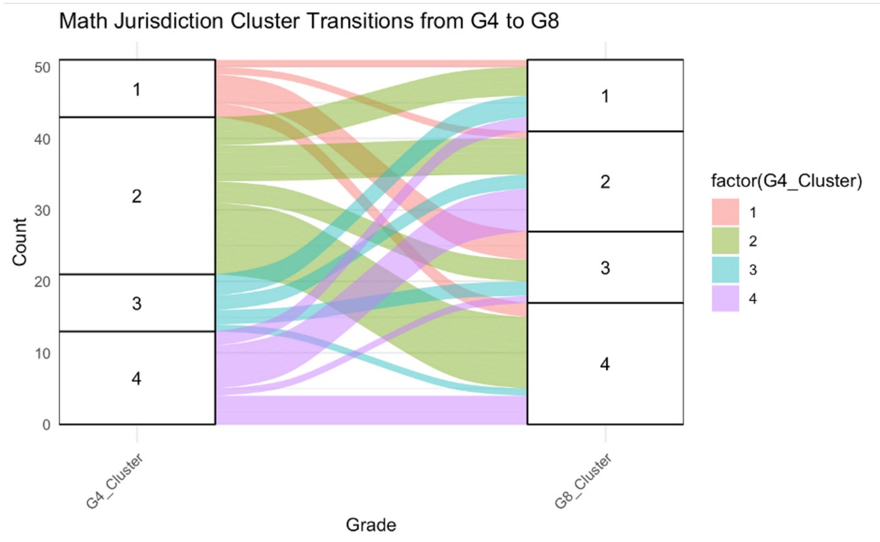
Achievement Gap Changes by Grades and Subjects

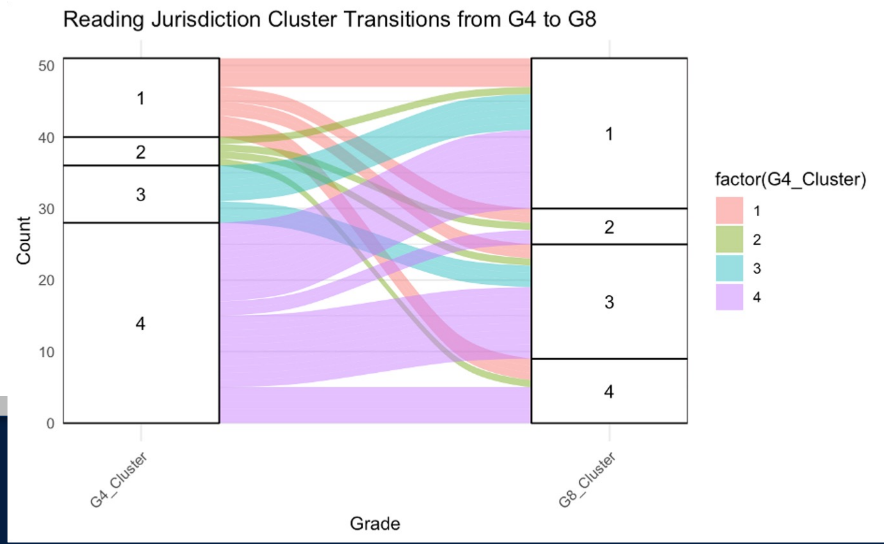
Alluvial Plots used to visualize cluster shifts:

- Transition from Grade 4 to Grade 8
- Math vs Reading.

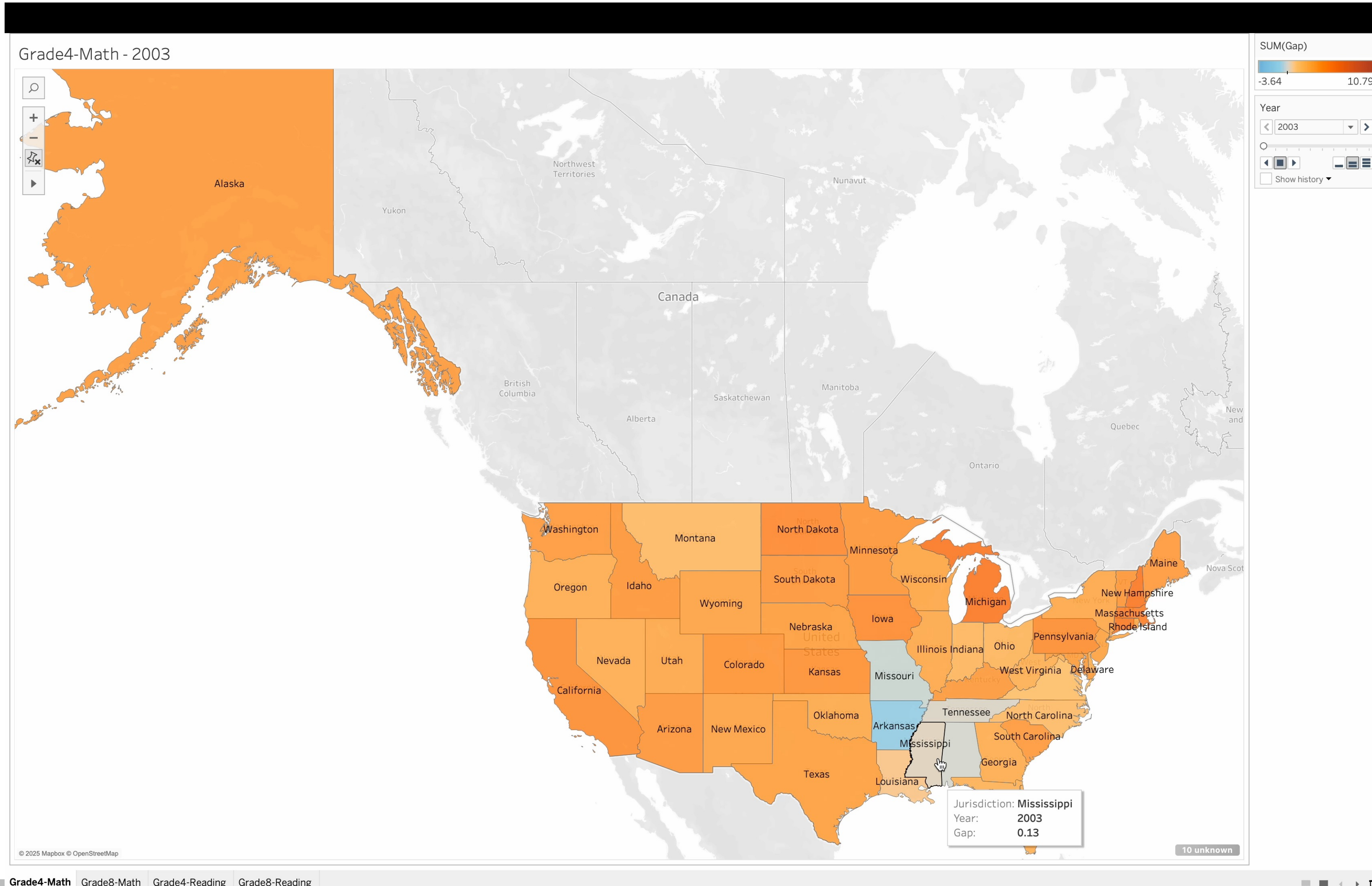
Findings

- **Math** shows many cross-cluster transitions, indicating less stability across grade.
- **Reading** shows more jurisdictions remaining in the same cluster or nearby clusters.
- **Reading is more stable than Math** across grade 4 and grade 8.

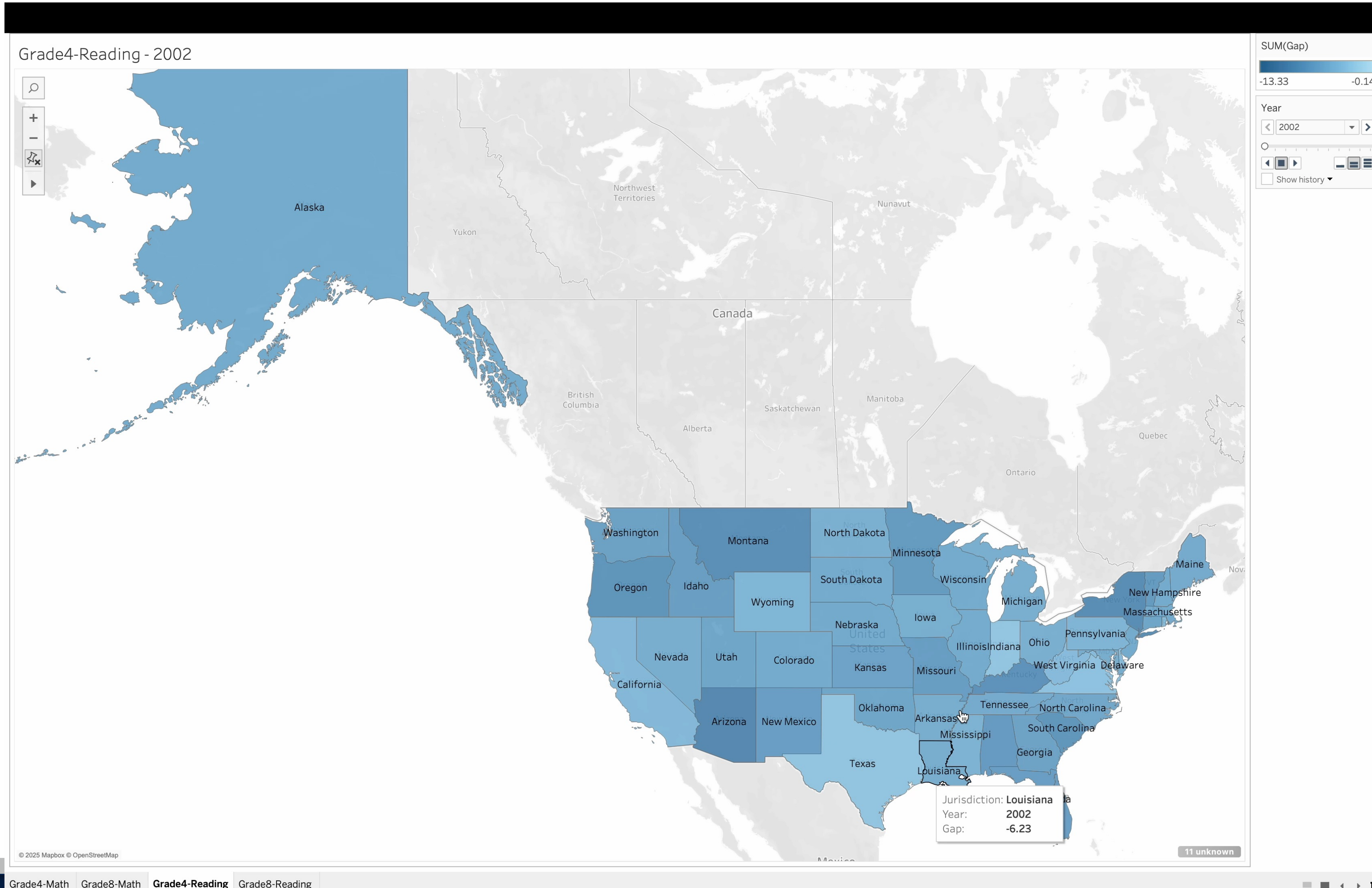




Grade 4 Math Achievement Gap by Gender Across Years



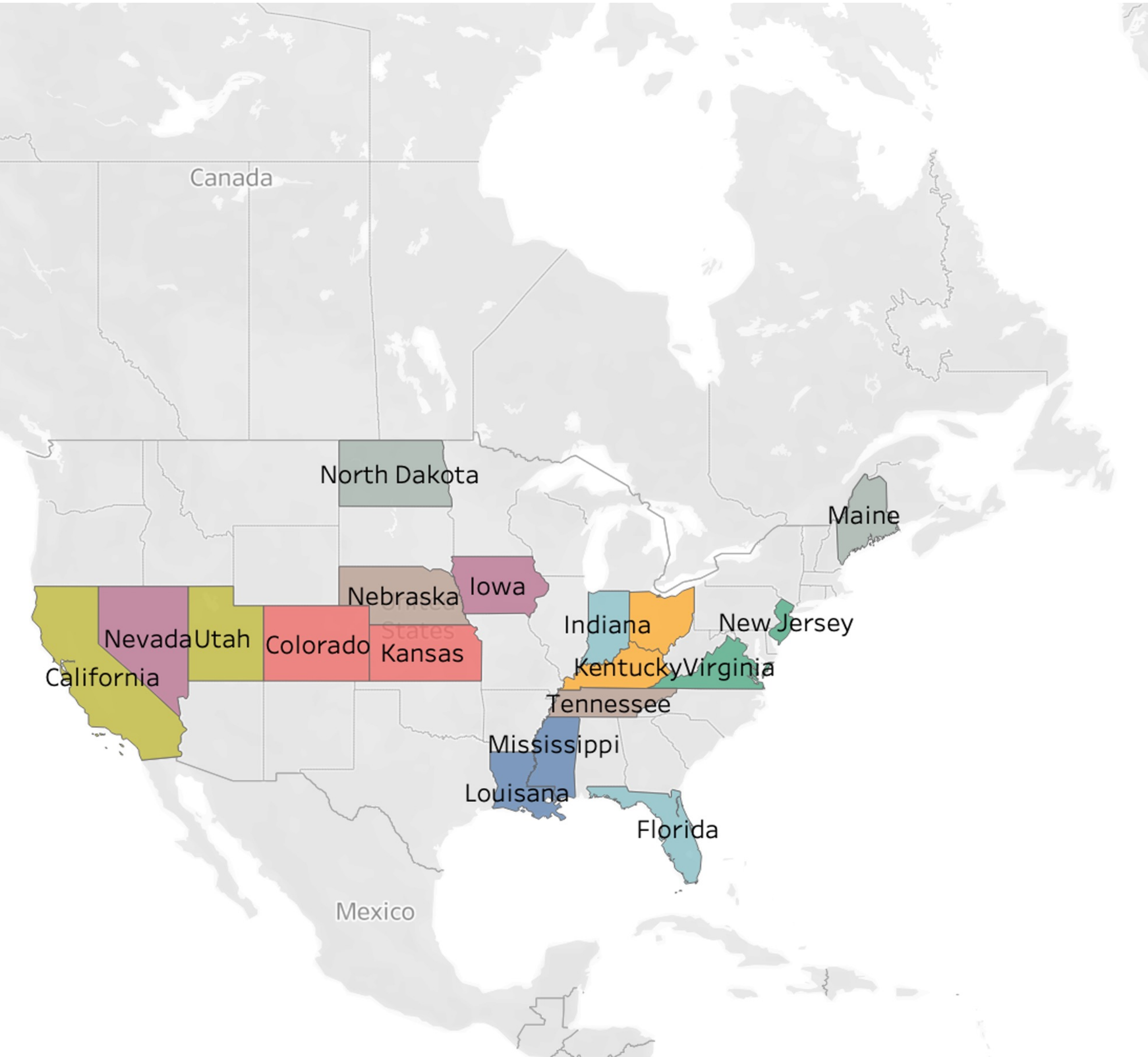
Grade 4 Reading Achievement Gap by Gender Across Years



Geographical Patterns shown in Achievement Gaps

- Nine state pairs consistently grouped together across all settings:
    - Kentucky & Ohio
    - California & Utah
    - Florida & Indiana
    - Louisiana & Mississippi
    - Colorado & Kansas
    - New Jersey & Virginia
    - Iowa & Nevada
    - Nebraska & Tennessee
    - North Dakota & Maine

- Indicates possible shared policies, demographics, or regional factors.



4 Discussion

Summary

- The sequence-based dynamic time warping similarity measurement and sequence clustering support **visualization on trajectory pattern** of achievement gaps across states, and identify **homogenous patterns across state clusters**.

- The achievement gaps between boys and girls significantly **enlarged in Math after COVID**.

- The achievement gaps between boys and girls is **less stable in math than in reading**, suggesting the educational policy or curriculum changes might impact more sensitively in math learning.

- The patterns of achievement gaps trajectory patterns are **more stable in Grade 8 than in Grade 4**, suggesting the younger group might be more impacted with the change of educational policy and curriculum development.

Limitation and Future Work

- This study provides a novel perspective on the impact of educational policies on student performance. Future research could **incorporate additional demographic variables, such as school type, socio-economic status (SES), and region, to analyze trajectory patterns**.

- Methodology developed in this study can be **generally extended to school districts, cities**, to track trajectories of students' growth, academic gaps by different groups.

- Developing a **centralized portal or data platform** could serve as a **valuable tool for tracking performance trends** in NAEP and other assessments over time.

- Findings from this study should be linked **more closely to state-level educational policies** to identify and address the root causes of achievement gaps.

AI Measurement and Data Science Lab

- Process data analytic methods
- AI item generation
- Psychiatry acuity measurement
- ML on missing data prediction
- Eye-tracking for ELL
- VR/AR in assessment

Thank you very much!

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