

# A Diagnostic Tool that Scales Student Voice through Semi-Automated Text Analysis and Qualitative Clustering

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James Colliander (Crowdmark and UBC)

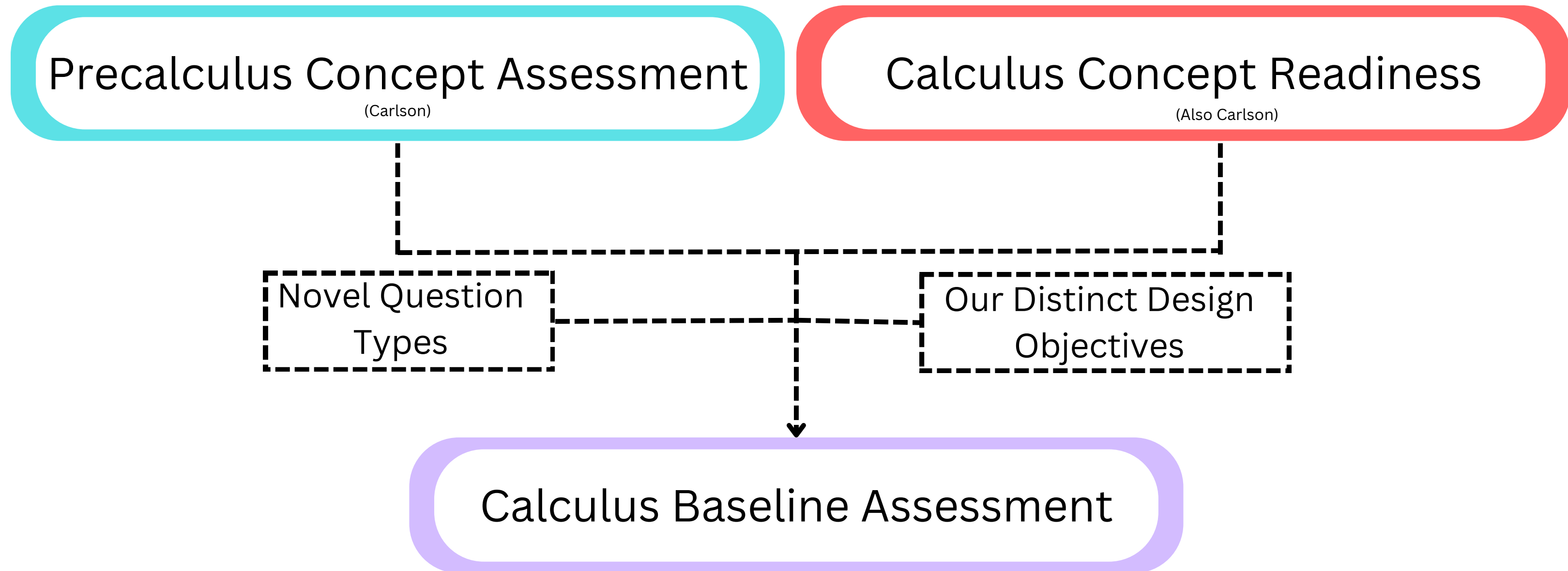


# CBA Motivation

- Math is a cumulative subject:
  - Student readiness can be gauged based on their mastery of past subjects.
- Expediency is paramount for a diagnostic assessment that gauges said masteries:
  - This is achieved using short multiple choice questions.

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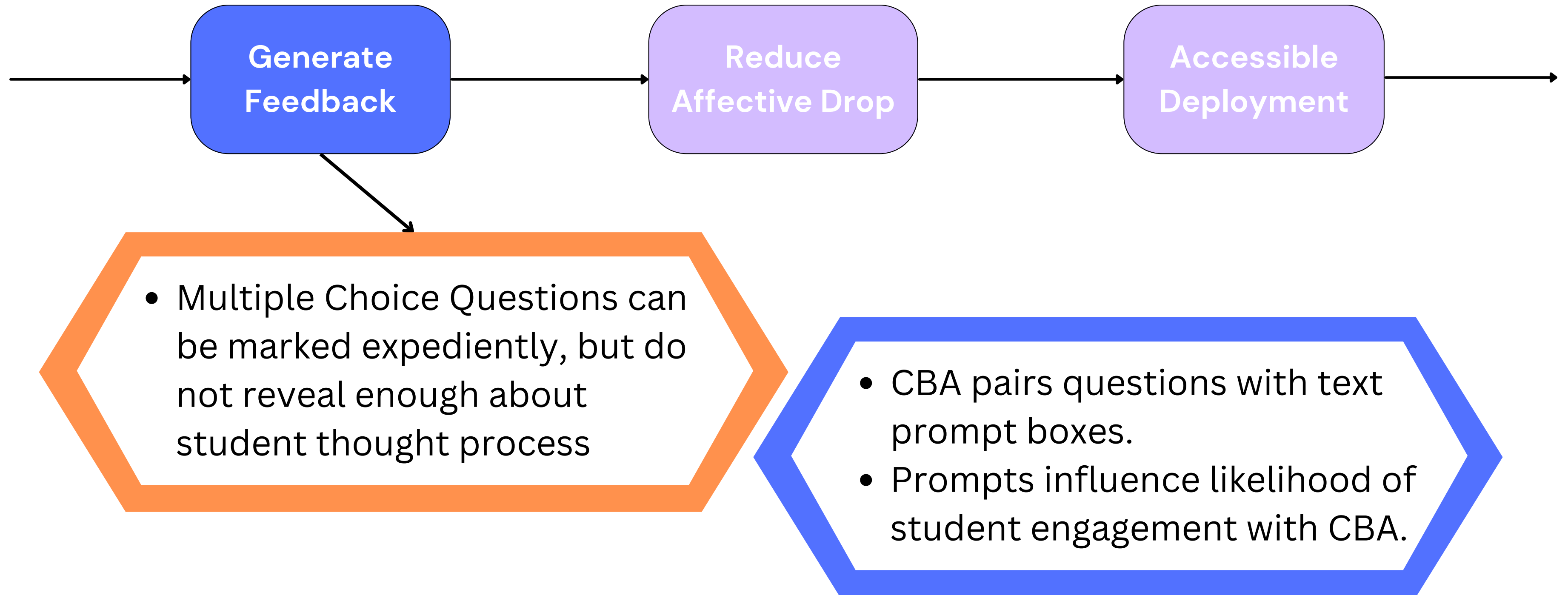


# CBA Design Objectives

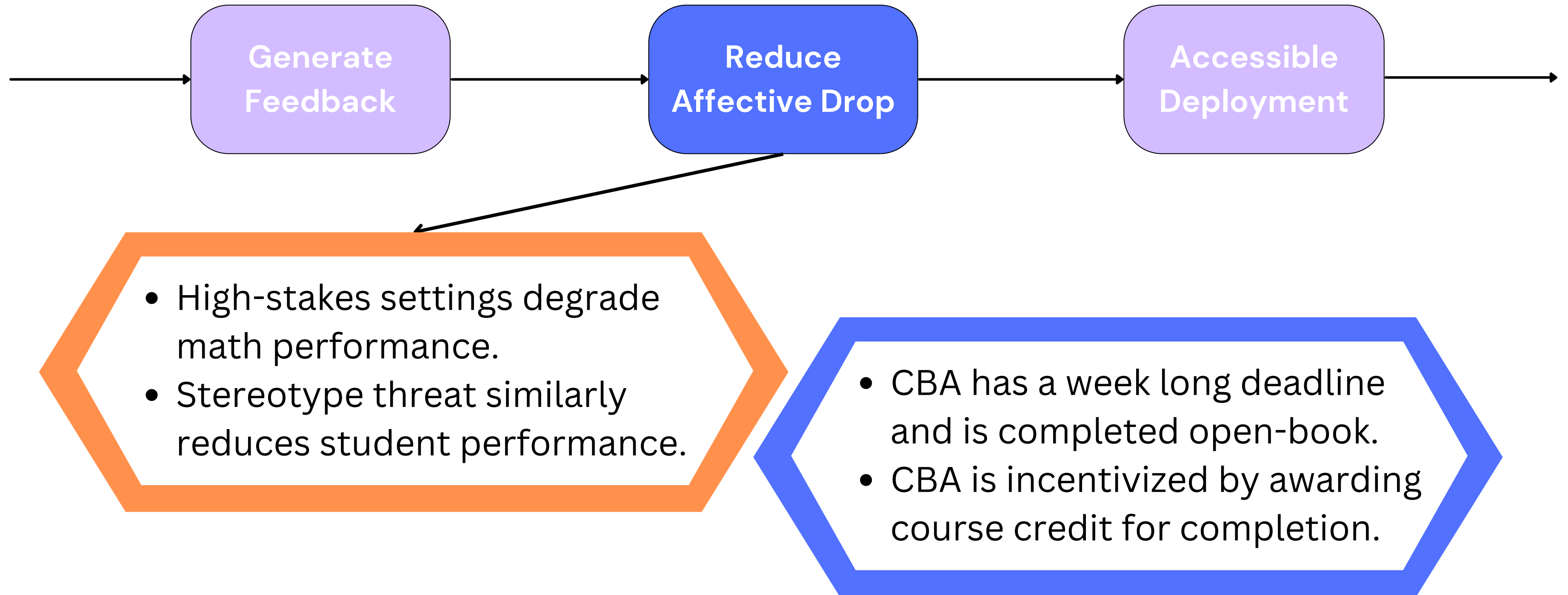
Our design objectives distinguish the CBA as its own distinct assessment.



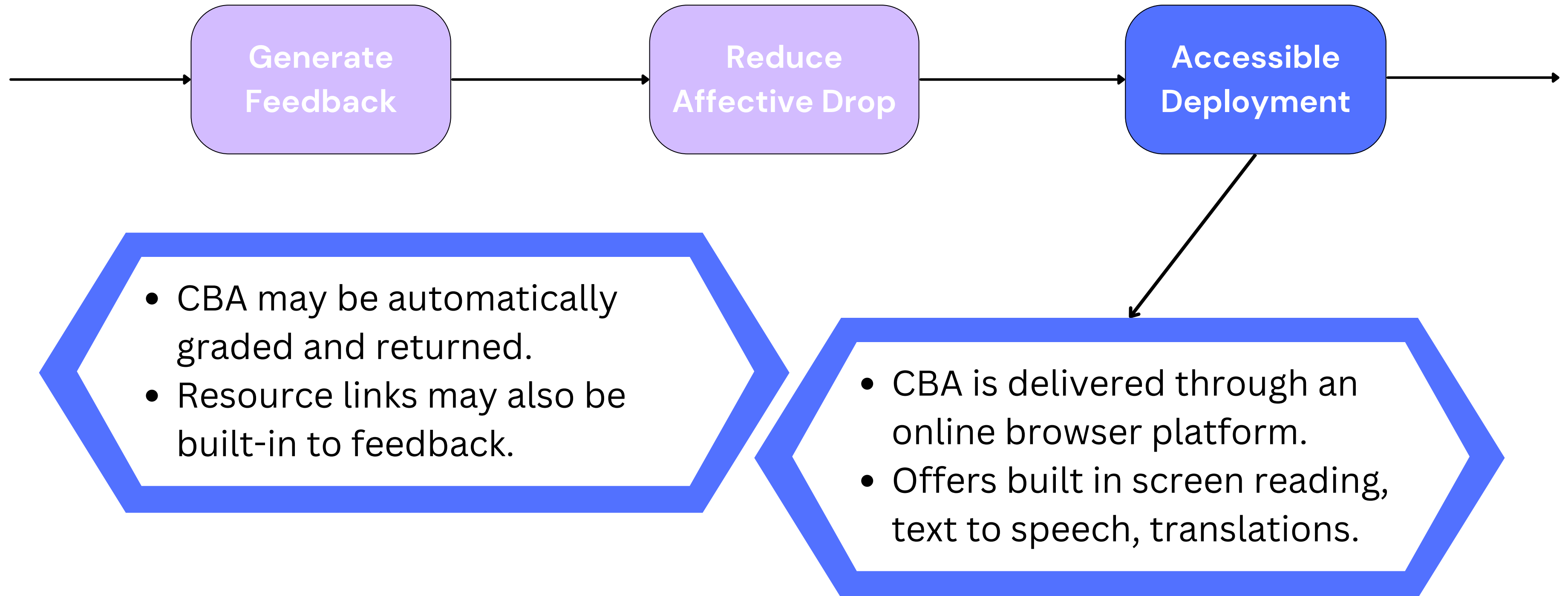
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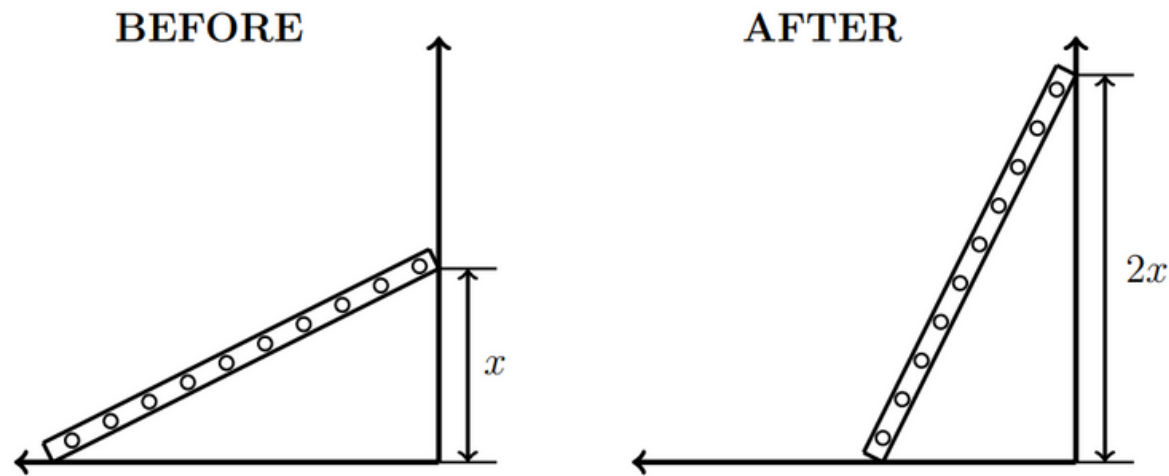
# CBA Design Objectives



# CBA Sample Question

## Q13a (1 point)

A ladder - of fixed length - is leaning against a wall. The ladder is adjusted so that the distance of the top of the ladder from the floor is twice as high as it was before it was adjusted.



The slope of the ladder is:

- ☐ Less than twice what it was before
- ☐ Exactly twice what it was before
- ☐ More than twice what it was before
- ☐ The same as what it was before
- ☐ There is not enough information to determine if any of  $a$  through  $d$  is correct.

## Q13b (0 points)

Explain the reasoning for your answer to Q13a in the box below.

[Edit](#) [Preview](#)

Please enter your response to Q13b

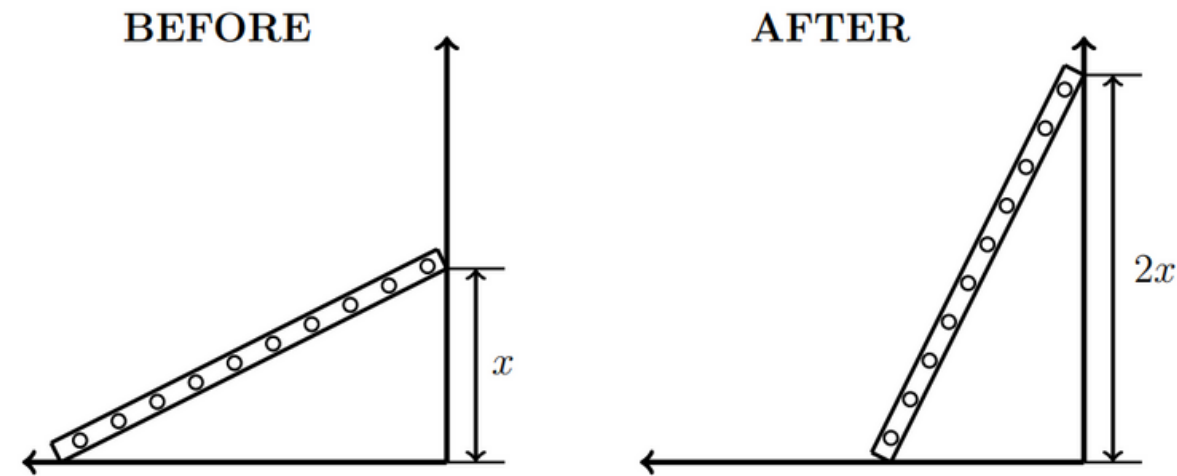
[Attach files](#) [Formatting tips](#)



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## Q13b (0 points)

Explain the reasoning for your answer to Q13a in the box below.

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The slope of a line equals rise over run. The height of the ladder (its rise) is being doubled, but since the ladder is fixed length this decreases the run. Because the directly proportional value is doubling and the inversely proportional value is decreasing, the slope will be more than twice its original value.\*

\* Fabricated example, not student data.


# Qualitative Coding Procedure

- We curate a qualitative codebook from scratch.

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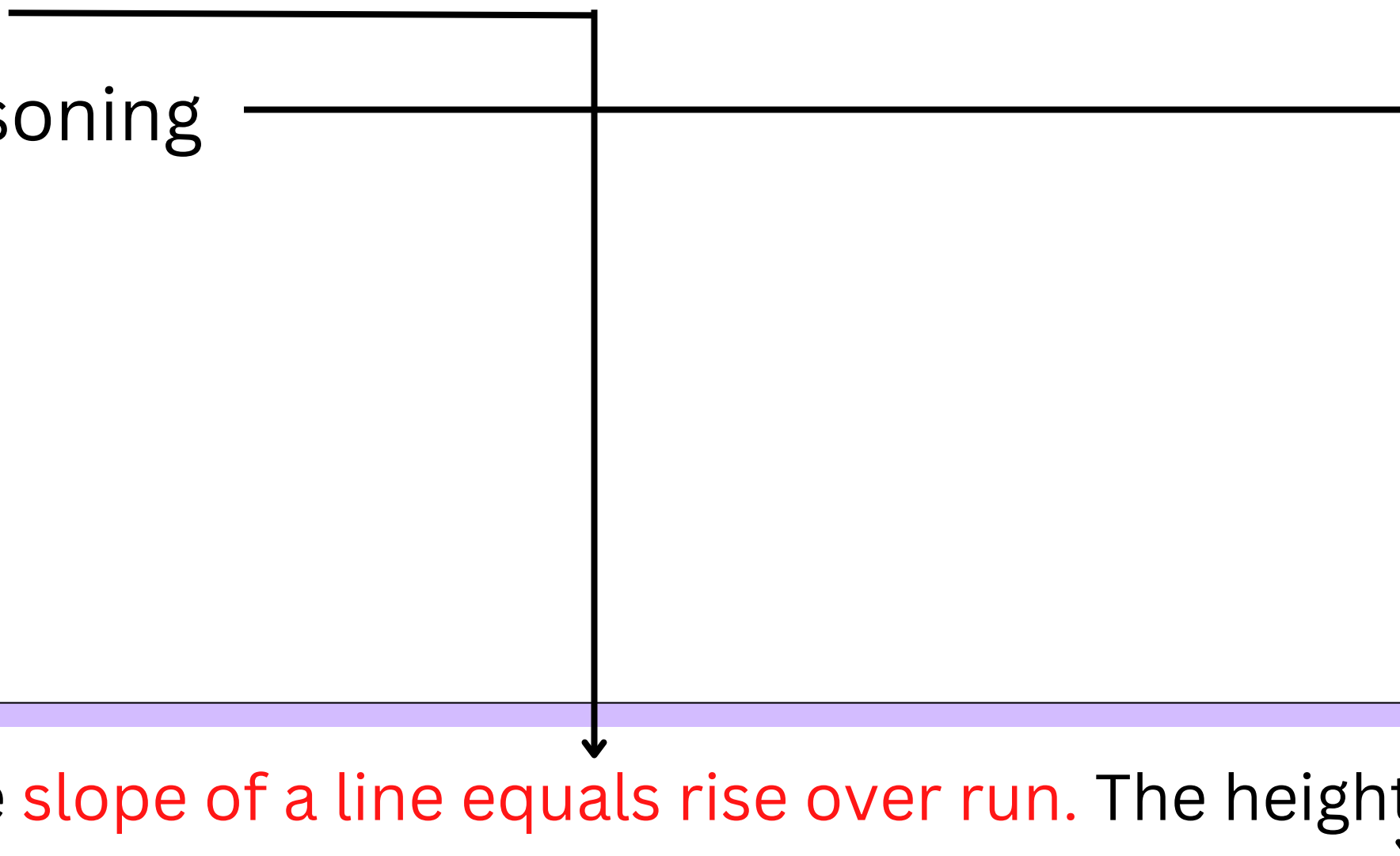
- We curate a qualitative codebook from scratch.
  - Implements Math Definitions



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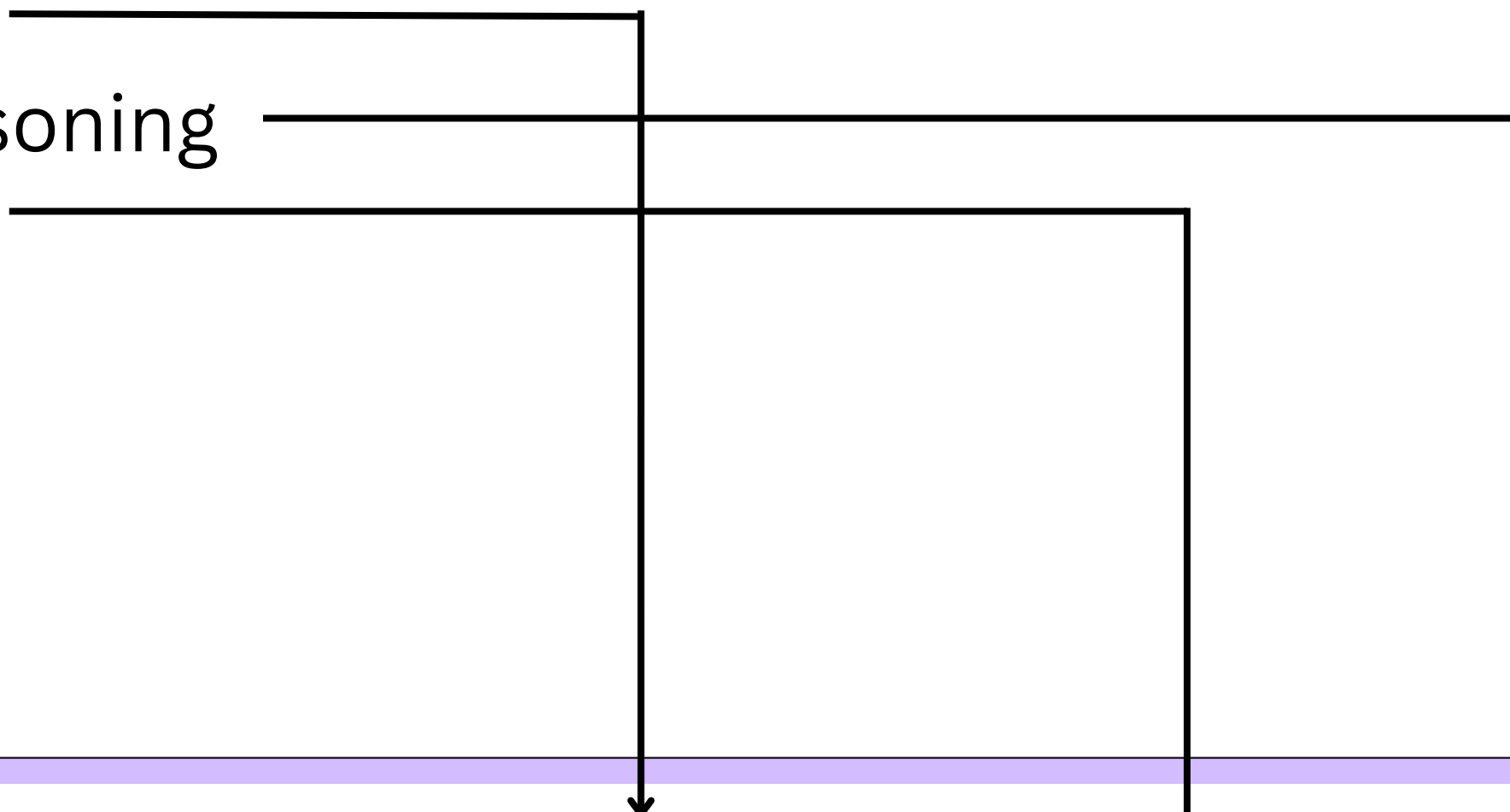
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  - Contextual Covariational Reasoning



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  - Contextual Covariational Reasoning
  - Understands Slope Behavior



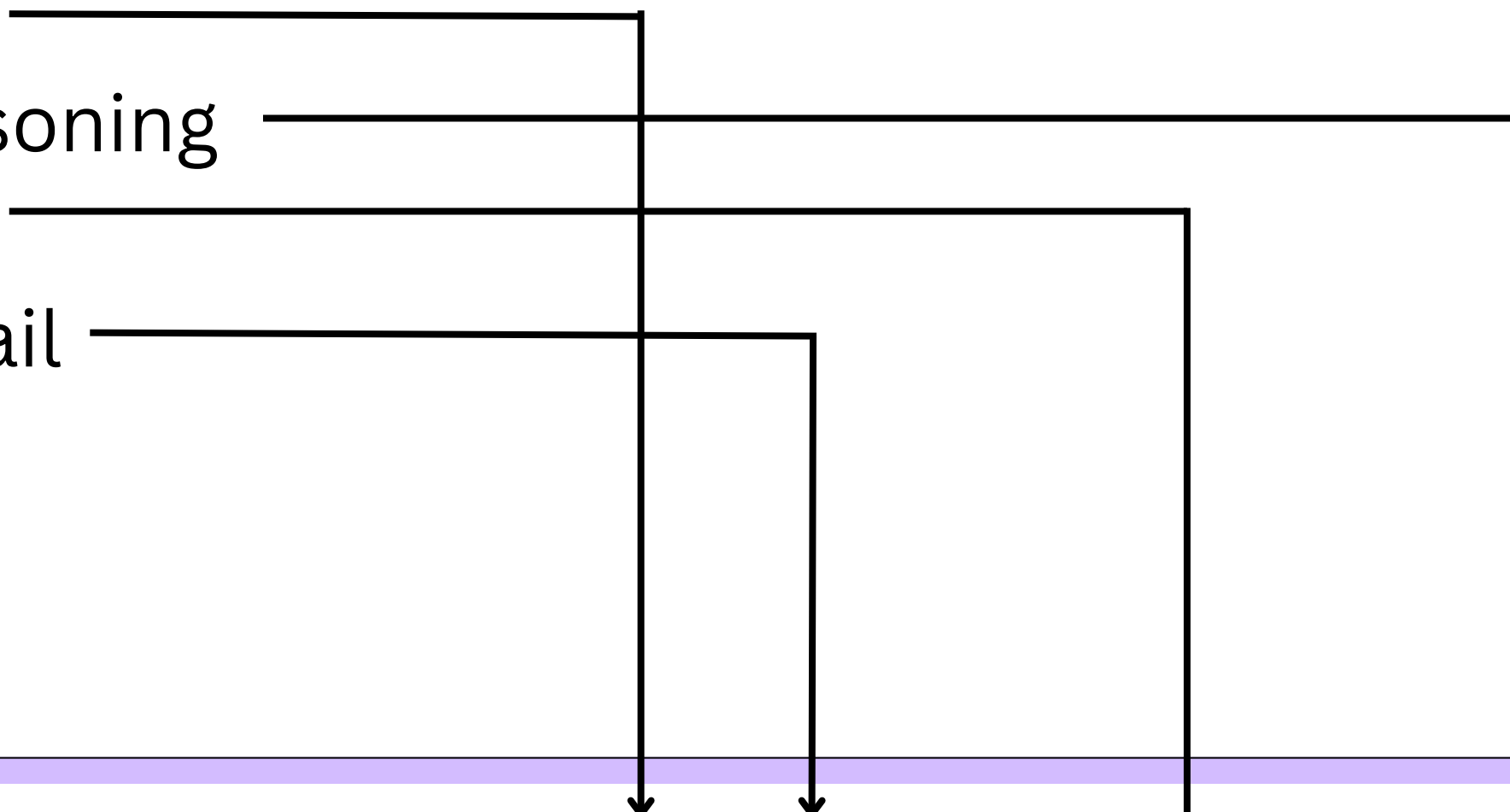
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The diagram consists of three horizontal lines extending from the list items to the right. From the end of the 'Implements Math Definitions' line, a vertical line goes down to the first arrowhead. From the end of the 'Contextual Covariational Reasoning' line, a vertical line goes down to the second arrowhead. From the end of the 'Understands Slope Behavior' line, a vertical line goes down to the third arrowhead.

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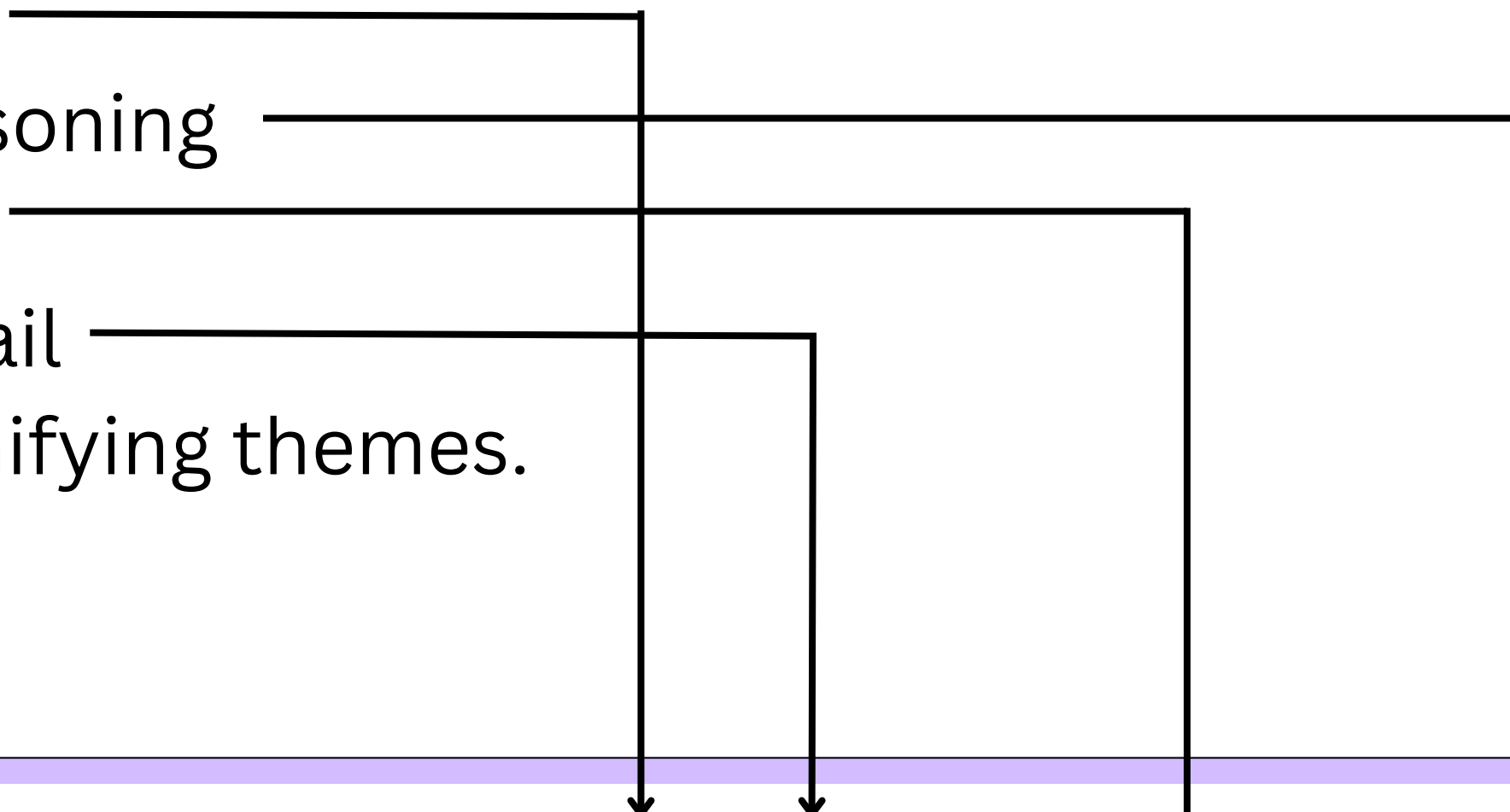
- Implements Math Definitions
- Contextual Covariational Reasoning
- Understands Slope Behavior
- Provides Comprehensive Detail



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- Similar codes are bundled into unifying themes.



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The diagram consists of four horizontal lines originating from the right side of the four sub-bullets under 'We curate a qualitative codebook from scratch'. These lines extend to the right and then turn downwards as arrows pointing to the text box. The first arrow points to 'The slope of a line equals rise over run'. The second arrow points to 'since the ladder is fixed length this decreases the run'. The third arrow points to 'directly proportional value is doubling and the inversely proportional value is decreasing'. The fourth arrow points to 'the slope will be more than twice its original value'.

# Qualitative Coding Procedure

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Algebra Skills

Math Relationship Skills

Solution Framework



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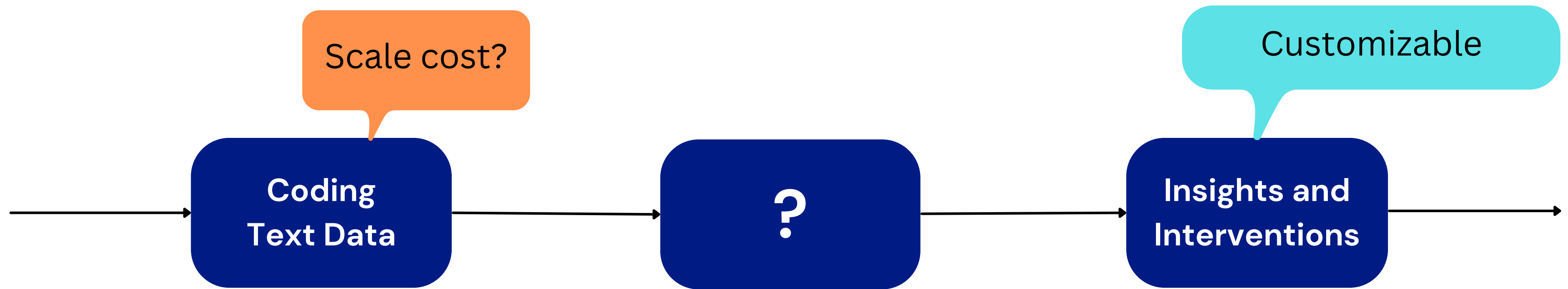
Visualization

Mathematical Language

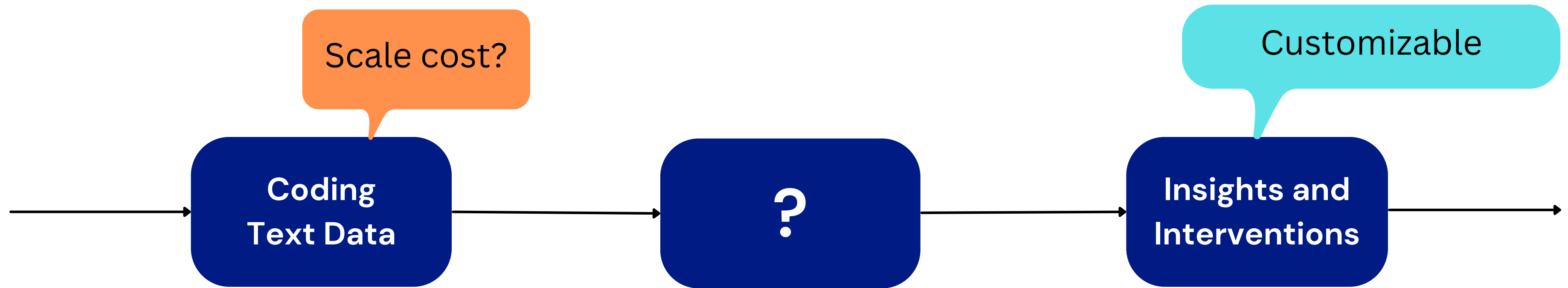
Contextual Reasoning

Heuristic View

# Our Methodology

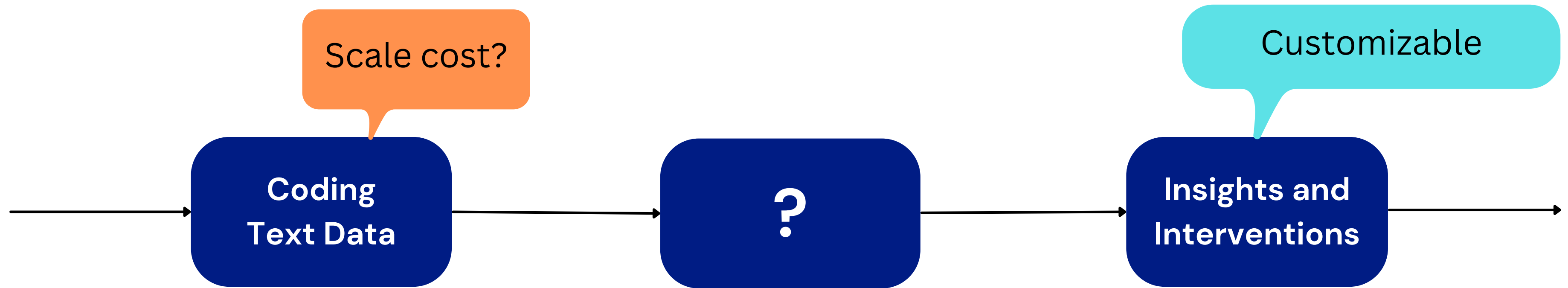


# Our Methodology



Qualitative coding provides quantifiable information about student aptitudes; however...

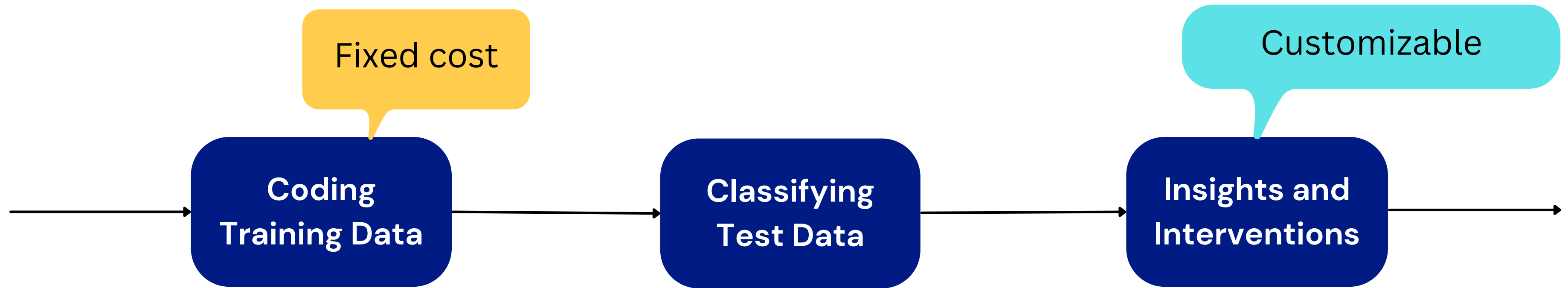
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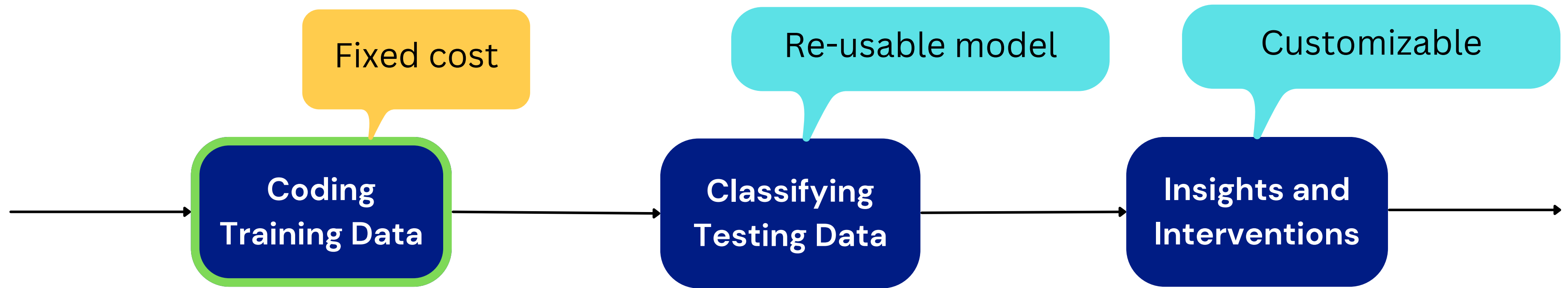
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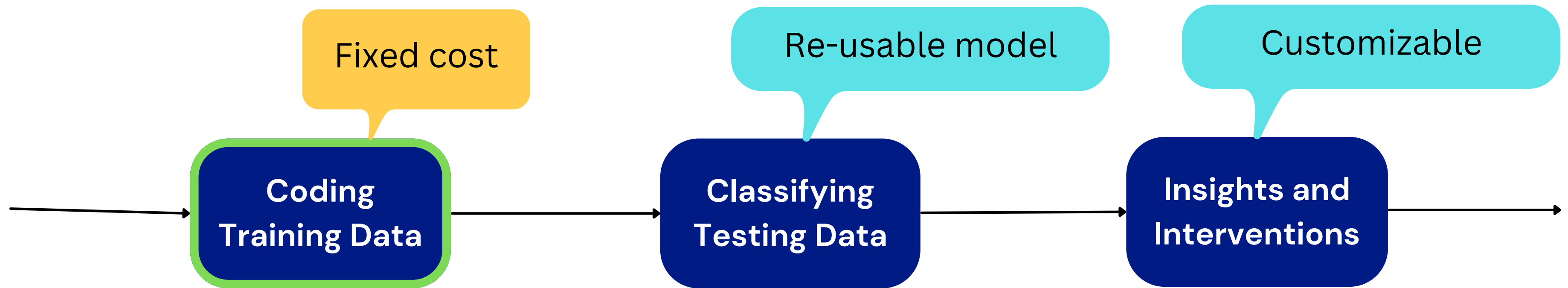
**This is a massive time investment!**  
Thankfully machine learning can automate this process!

# Our Methodology

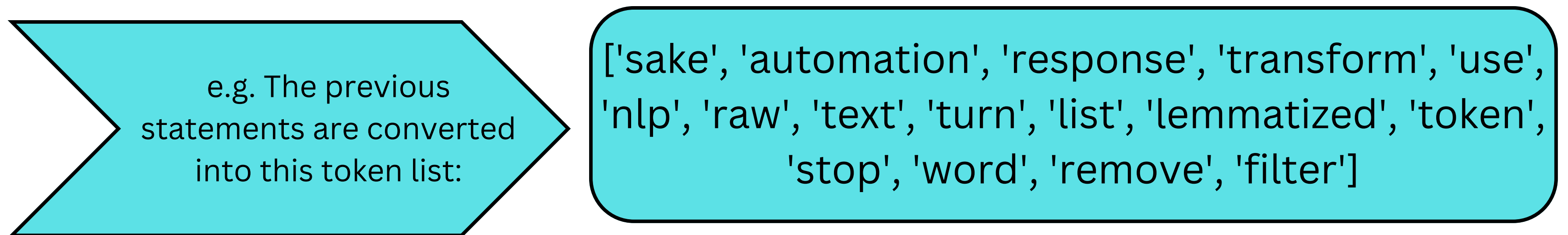


- For the sake of automation, each response is transformed using NLP.
  - The raw text is turned into a list of lemmatized tokens that have had their 'stop' words removed by a filter.

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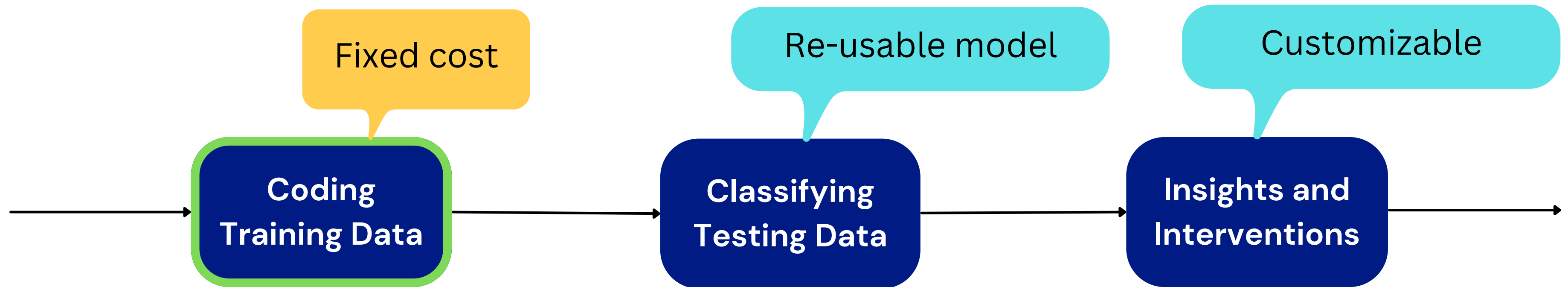


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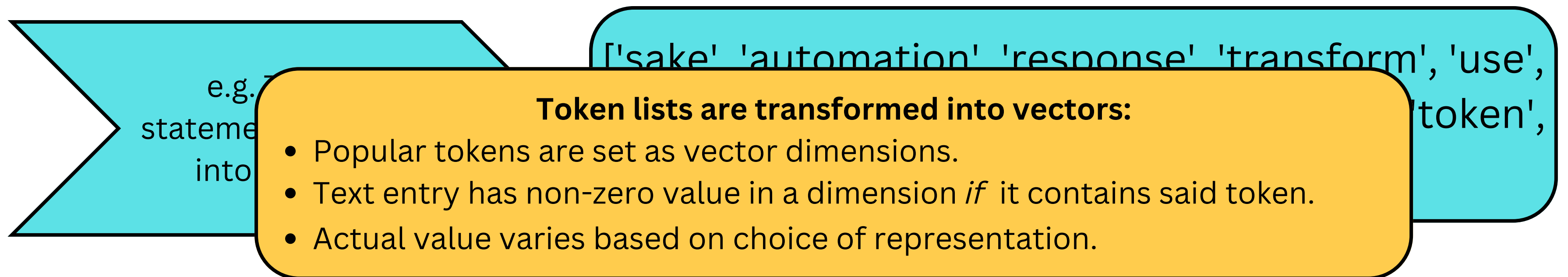




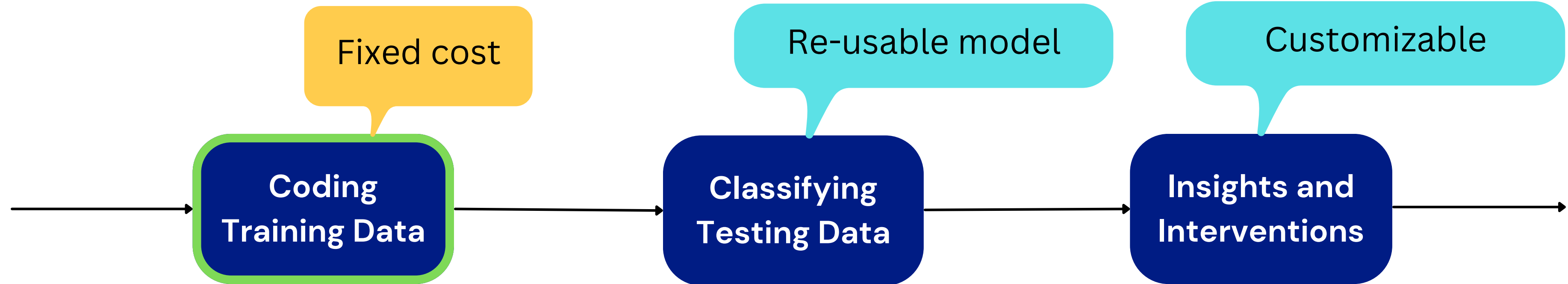
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e.g. [ 'sake' 'automation' 'response' 'transform', 'use', 'token' ]

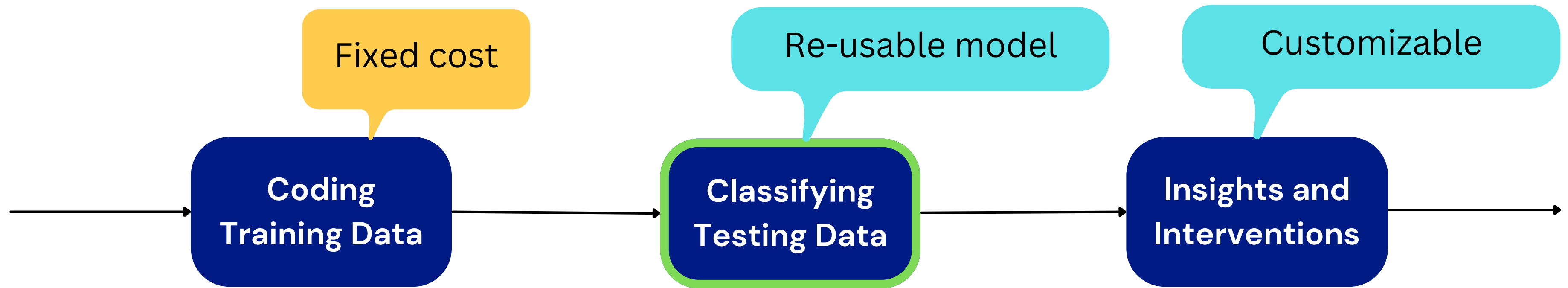
Token lists are transformed into vectors:

Pop as n at va

e.g. The tokens can translate to a vector with these dimensions.

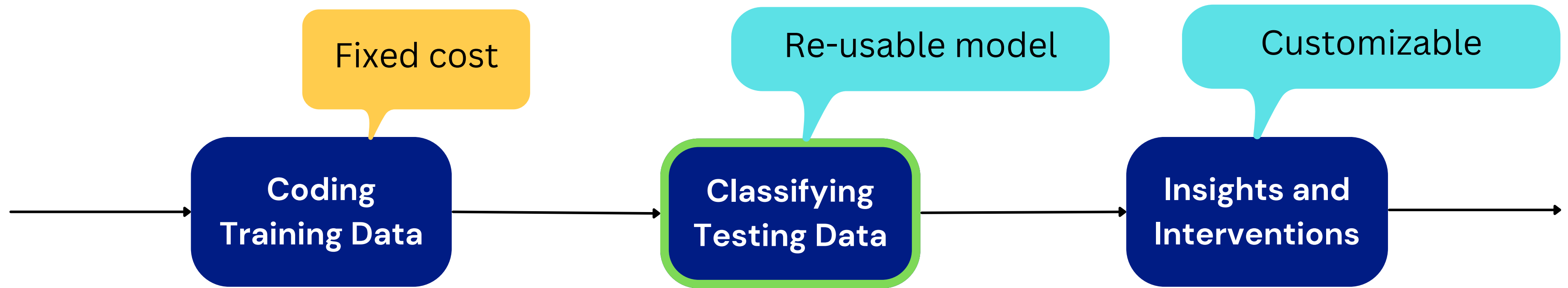
automation	computer	filter	math	nlp	plus	subtract	token	use
1	0	1	0	1	0	0	1	1

# Our Methodology



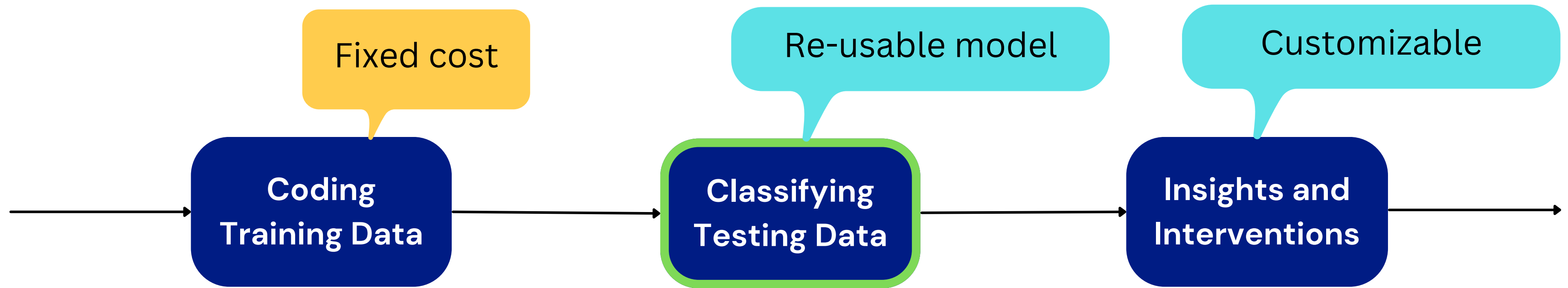
- Transformed vectors serve as input for our ML model ( $x$ )
- A separate vector serves as output ( $y$ )
  - Vector entries signal presence of a qualitative code.
  - Text responses possess own code signature.

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- Using  $(x,y)$  pairs, a ML model can learn to qualitatively code!
  - We use gradient boosting machines to do this.
  - GBMs iteratively design sequence of decision trees which classify vectors.

# Our Methodology



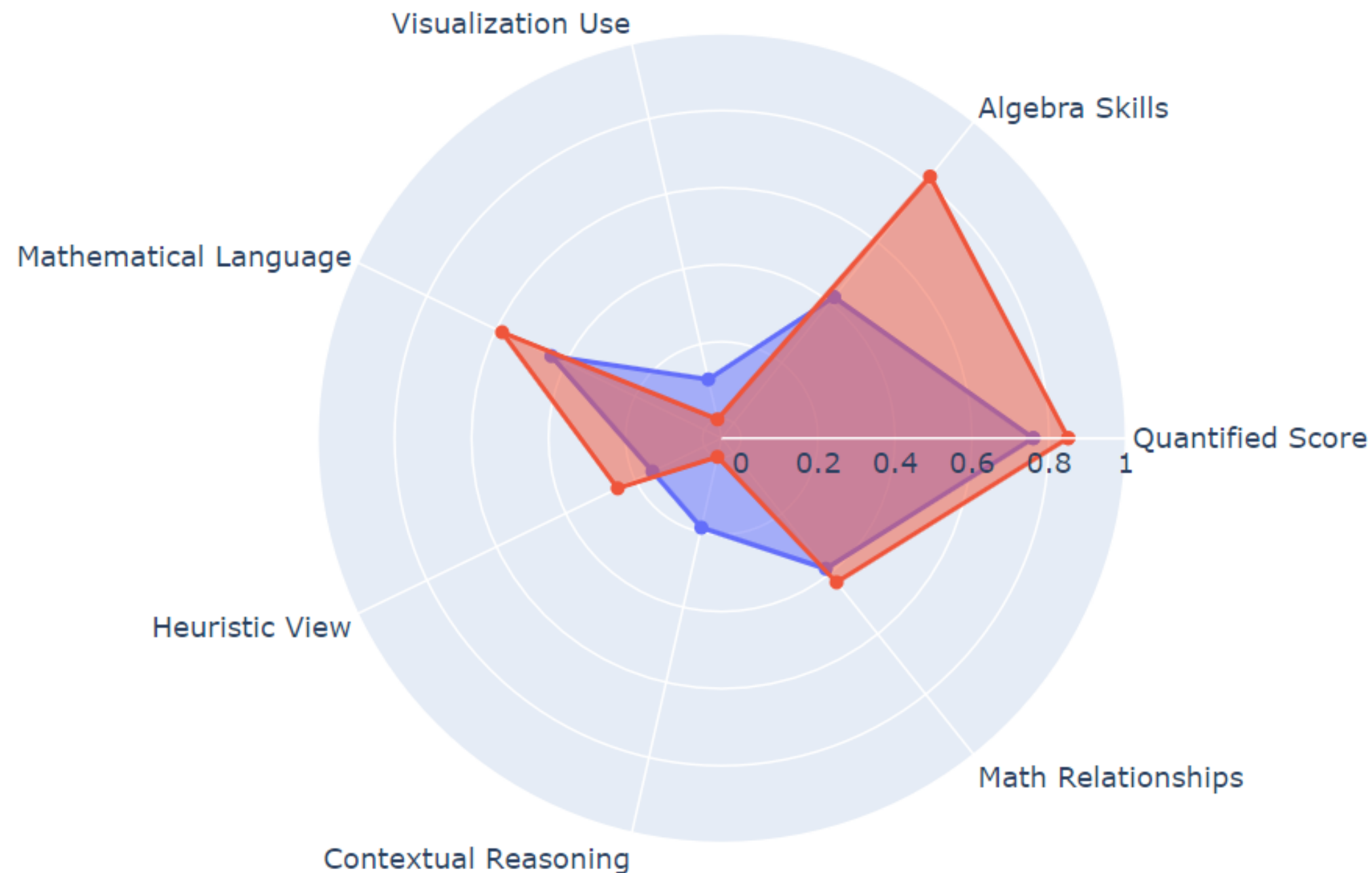
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    - We must discern where to apply models based on code frequency.

Theme \ Question	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Algebra Skills (11)																				
Math Relations (8)																				
Solution Frame (11)																				
Algebra Traps (5)																				
Solution Misint. (13)																				
Knowledge Gap (1*)																				
Math Language (12)																				
Heuristic View (4)																				
Visualization Use (2)																				
Context Reason (3)																				
Attachment Use (20*)																				

- Theme presence across CBA questions:
  - Green cells indicate > 10% frequency.
  - Yellow cells indicate > 0 % frequency.

Theme \ Question	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Algebra Skills (11)	Green	Green	Green	Green	Green	White	Orange	Green	Orange	Green	Orange	Green	Orange	Green	Orange	Green	Orange	Orange	Green	White
Math Relations (8)	White	White	White	White	White	Green	Green	White	Green	White	Green	Orange	Green	White	Green	Green	Orange	Green	White	White
Solution Frame (11)	Green	Green	Green	Green	Green	White	Orange	Green	Green	Green	Green	White	White	White	White	Green	White	Green	White	Orange
Algebra Traps (5)	Green	Green	White	Orange	Orange	White	Orange	Orange	Green	White	White	Green	Green	Orange	White	Orange	Orange	White	White	White
Solution Misint. (13)	Orange	Orange	Green	Orange	Orange	Green	Green	Green	Orange	Green	Green	Green	Green	Green	Green	Orange	Green	Orange	Green	Green
Knowledge Gap (1*)	Orange	Orange	White	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
Math Language (12)	White	Orange	Green	Orange	Orange	White	White	Green	White	Green	White	Green	Green	Green	Green	Green	Green	Green	Green	Green
Heuristic View (4)	Orange	Orange	Orange	Orange	White	Green	Green	White	White	White	White	Orange	Green	Orange	Orange	White	Orange	Orange	Green	White
Visualization Use (2)	White	White	Orange	Orange	White	Orange	Green	White	White	Orange	White	White	White	Orange	Green	Orange	White	Orange	Orange	White
Context Reason (3)	White	White	White	White	White	Green	White	Orange	White	White	Green	Orange	White	White	White	White	White	White	Orange	Green
Attachment Use (20*)	Green	Green	Green	Green	Green	Orange	Green	Green	Orange	Green	Orange	Green	Orange	Green	Orange	Green	Green	Green	Green	Orange

# Data Visualization with Spider Plots



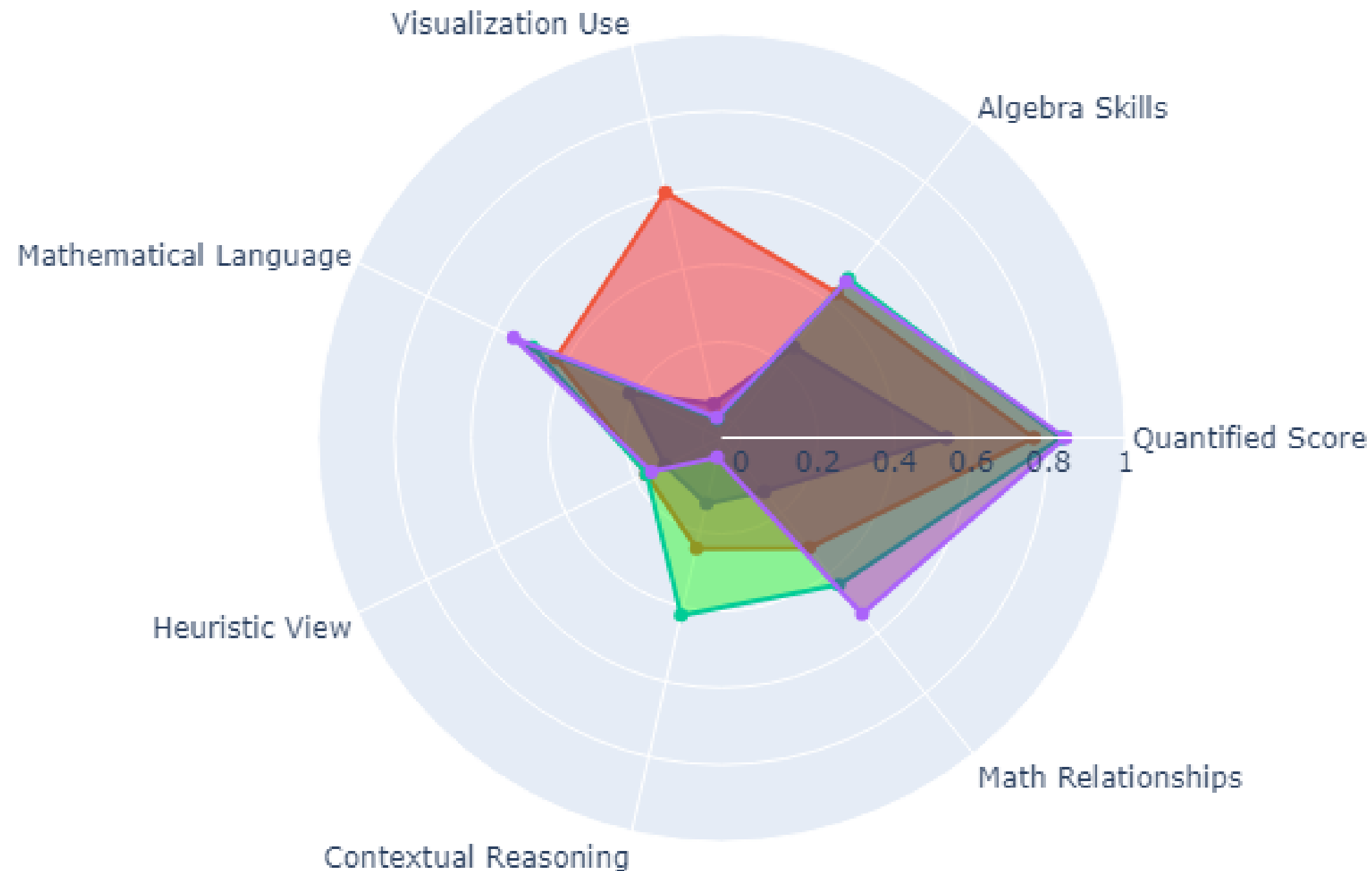
## Collating Student Dimensions:

- We standardize the fraction of flagged theme instances as a single dimension.

*Six themes are joined with CBA score to create a profile of student readiness. The red plot shows the profile of a random student while the blue plot shows the averaged profile of every student in the cohort.*



# Clustering Student Cohort



*Four spider plots each depicting the same seven student attributes; each plot is the centroid of a student cluster where: cluster A (blue) contains 147 students, cluster B (red) contains 106 students, cluster C (green) contains 188 students, cluster D (purple) contains 222 students.*

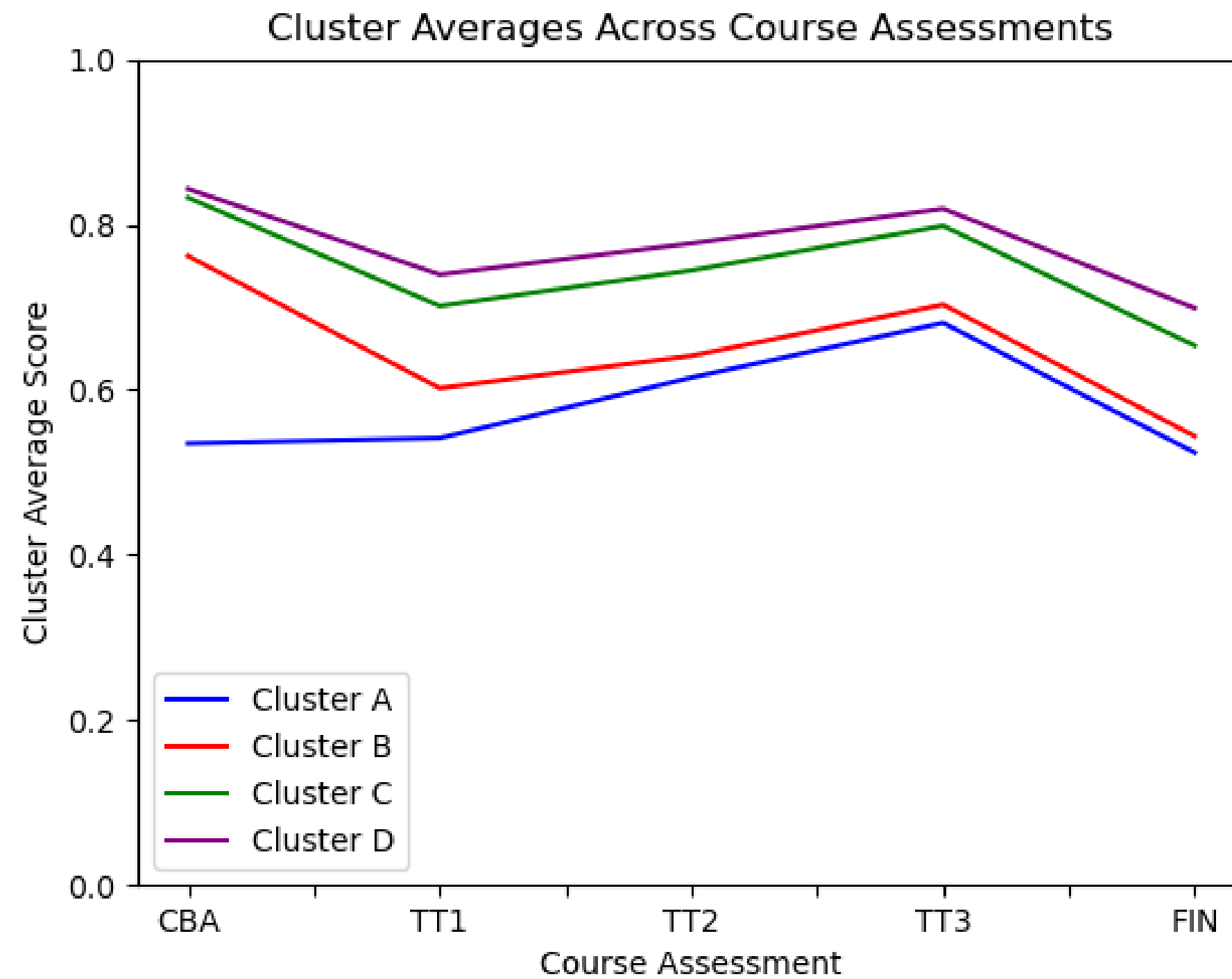
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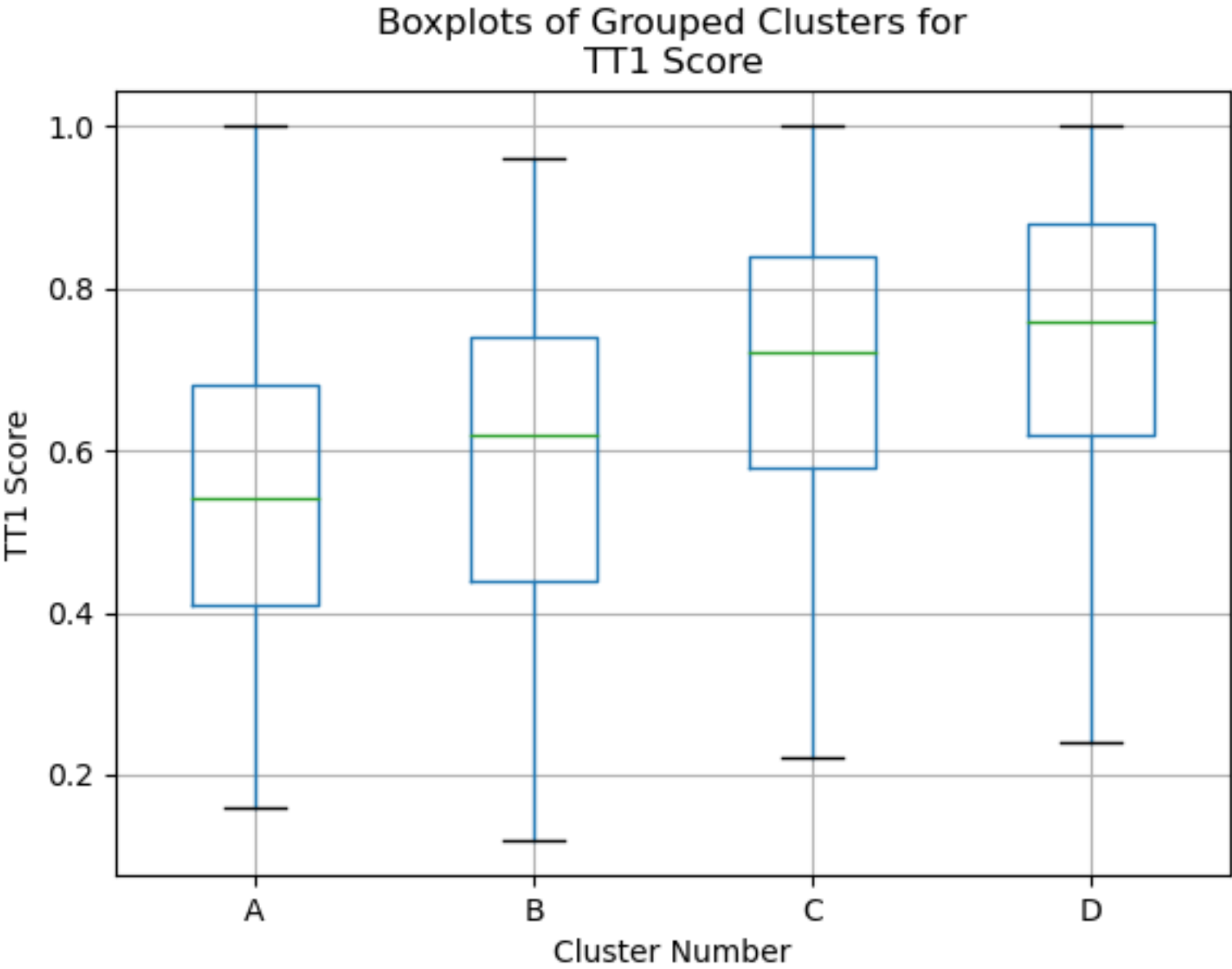
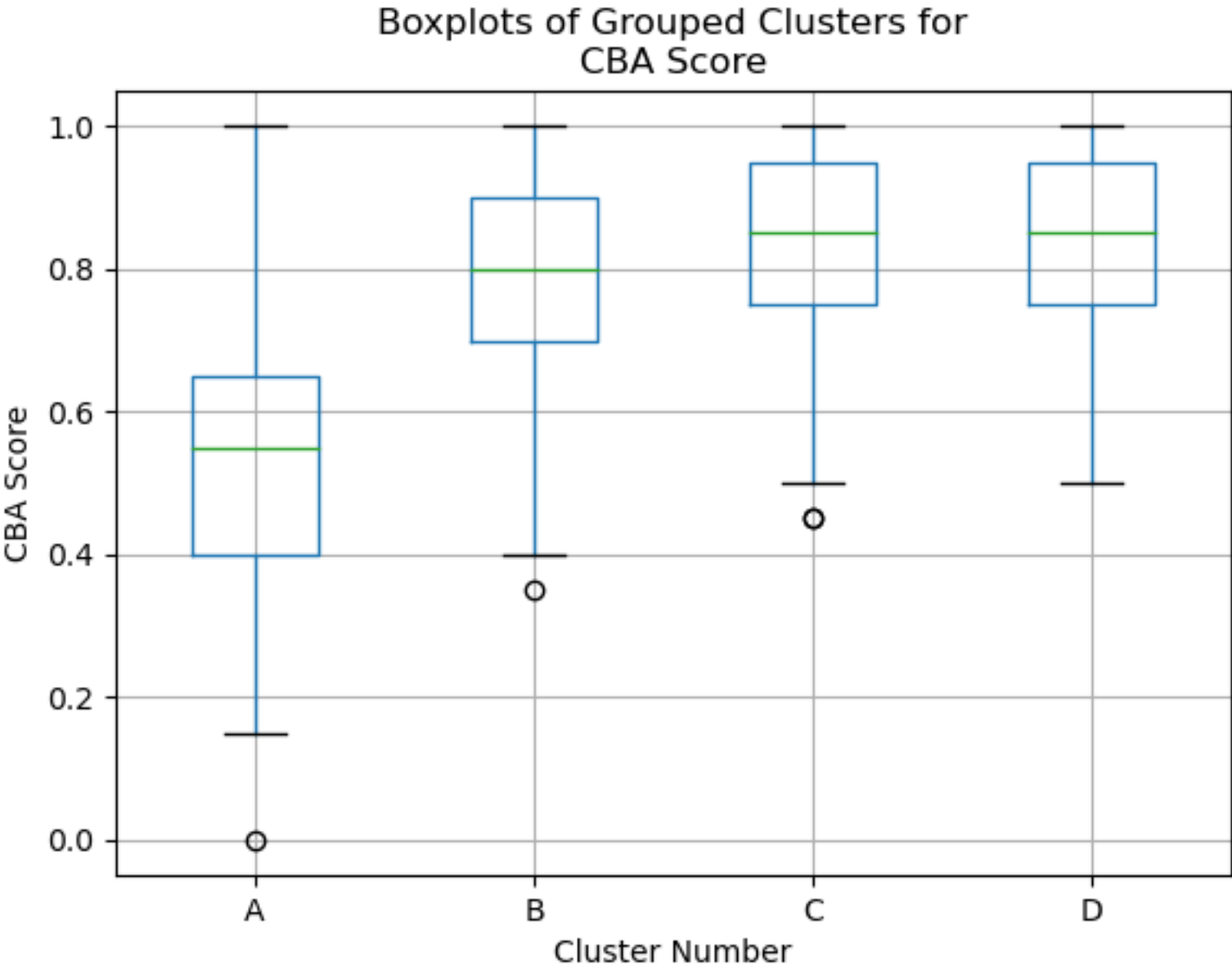
## Using k-clustering:

- We partition students based on dimensional distance from one another.

## Tracking Cluster Performance:

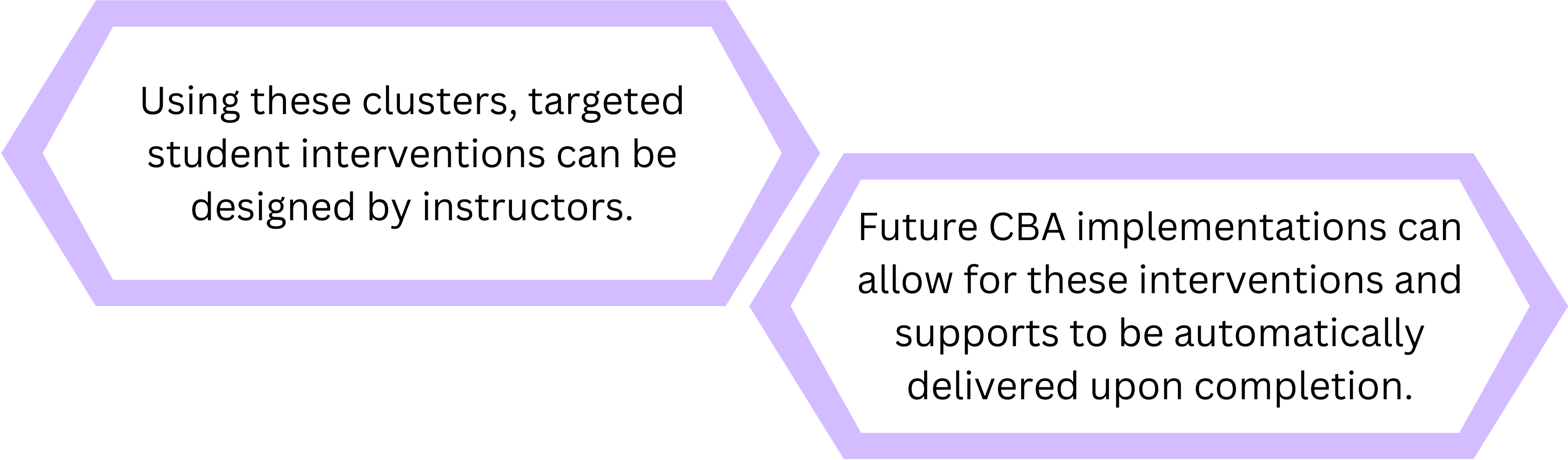
- We track cluster performance across a semester for longitudinal observation.

# Clustering Student Cohort



*Boxplots depicting spread of student scores on math assessments when cohort is partitioned by student cluster.*

# Concluding Remarks



Using these clusters, targeted student interventions can be designed by instructors.

Future CBA implementations can allow for these interventions and supports to be automatically delivered upon completion.

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**THANK YOU FOR YOUR TIME!**

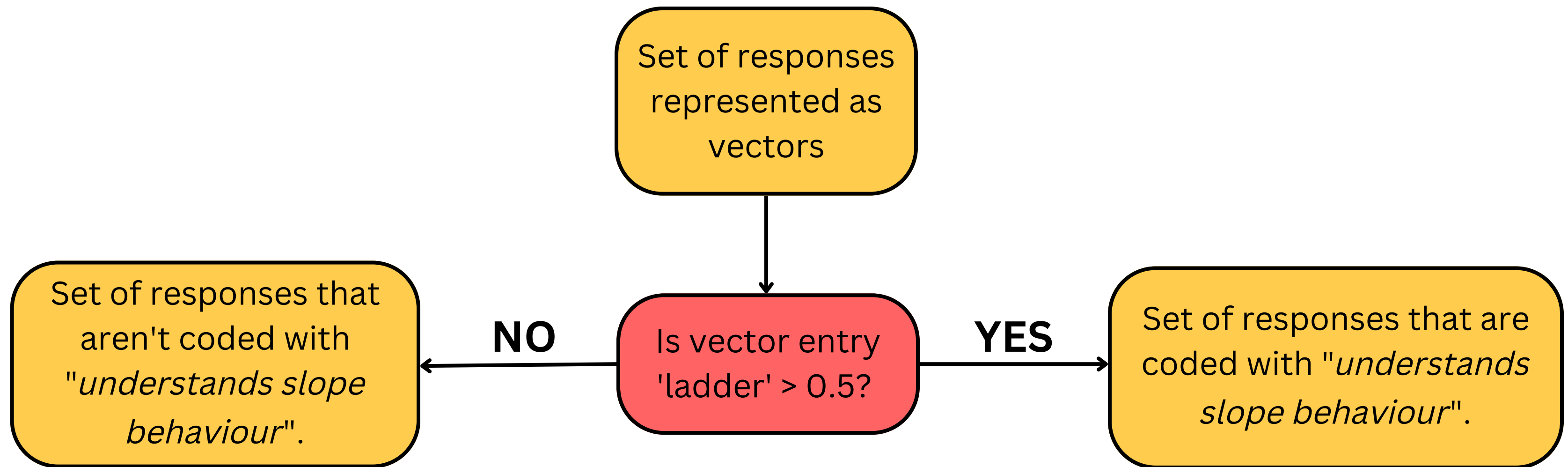
Please ask away with any questions you may have!

*Or visit our  
Github for a  
demo!*



# Gradient Boosting Machine Classification

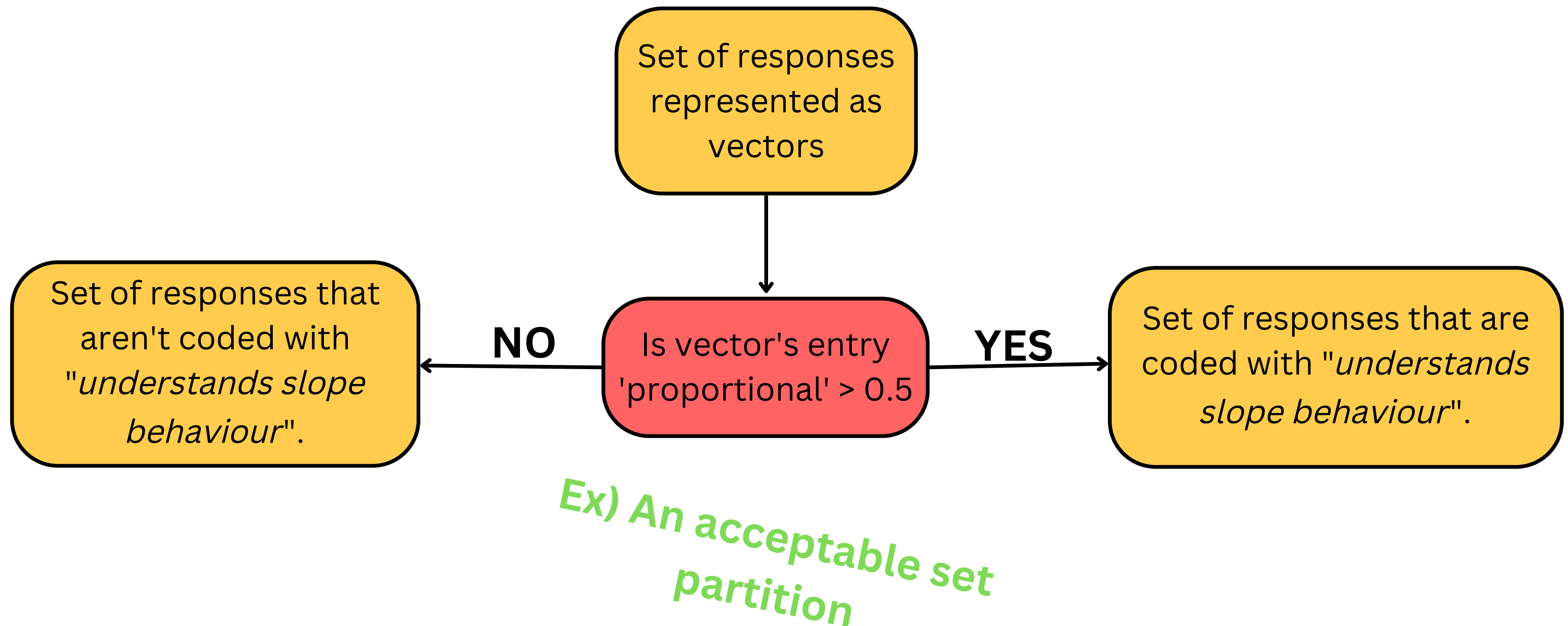
- The GBM is a decision tree that classifies the vector data.
  - The GBMs classification attempts to properly sort the labeled input.
  - It does this by partitioning the data with a one dimensional hyper-plane.



**Ex) A terrible set partition**

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# Gradient Boosting Machine Classification

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  - The GBMs classification attempts to properly sort the labeled input.
  - It does this by partitioning the data with a one dimensional hyper-plane.
- Hundreds are built and discarded as a **best** classifier is iteratively designed.
  - Weak learners support the tree by reclassifying residuals.
- Separate, parallel GBMs must be trained for each code.
- Cross-validation grid search finds each model's best parameters:
  - parameters: sample size, tree depth, number of estimators, learning rate.
- Using the trained model:
  - Influential tokens for partitioning can be examined.
  - New data can be automatically coded by the model.