Twist and Turn: Examining the Mind's Movements in Stereochemistry

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INTRODUCTION

- **Stereochemistry** involves the 3D arrangement of atoms in molecules and these arrangements affect reactivity and interactions. Chemistry instruction frequently includes **3D molecular representations** to help students **visualize** isomers, stereocenters, chirality, and conformations.
- Stereochemistry presents a significant challenge in organic chemistry, largely due to the complexity of **spatial recognition** required to understand 3D molecular arrangements.
- Prior research highlights the cognitive load such rotations place on learners and their correlation with **spatial reasoning skills**. Several studies show positive correlations between spatial ability & chemistry learning.[1] Moreover, students begin organic chemistry with varying experiences and abilities in **spatial cognition**, which can be a barrier to learning in organic chemistry.
- To better understand how to teach the visualization standpoint of stereochemistry a series of **mental rotations** & **transformations** were tested and analyzed.

Research Questions:

How is stereochemistry taught from a visualization standpoint?

What kinds of mental rotations and levels of abstraction do students encounter in organic chemistry?

METHODS

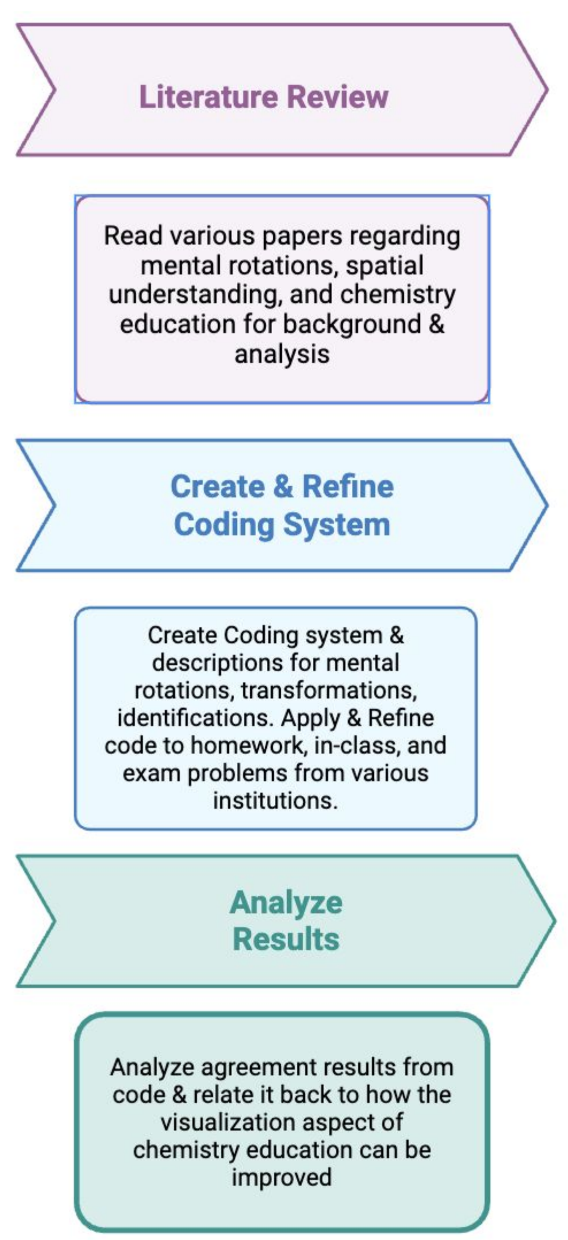
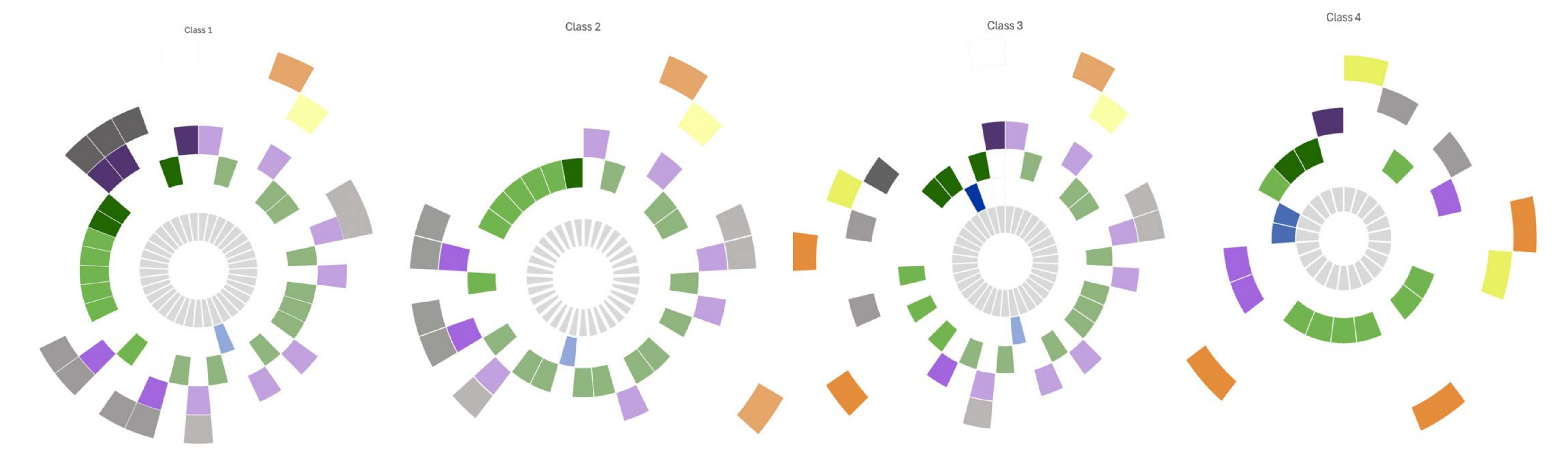


Figure 1. Figure above represents the flow in which the study was conducted

- Stereochemistry problems from instructional materials, homework, and exams across four classes at two universities were coded for the minimum mental rotation needed to determine stereochemical relationships.
- Four researchers collaboratively coded all samples to establish a consistent coding scheme and identify necessary rotation types.
- After coding, modified sunburst diagrams were created to visualize the progression of required mental rotation types across each class's curriculum.

RESULTS ON MENTAL ROTATIONS ACROSS STEREOCHEMISTRY CURRICULUM



Class 1

	Most practiced rotation	Second practiced rotation
In-class	A0, SBR (10 each)	
HW	A0 (6)	180y (4)
Exam	SBR (4)	A0, 180y (3 each)

Class 2

	Most practiced rotation	Second practiced rotation
In-class	A0 (16)	SBR (9)
HW	A0 (6)	180y (4)
Exam	A0 (1)	N/A

Class 3

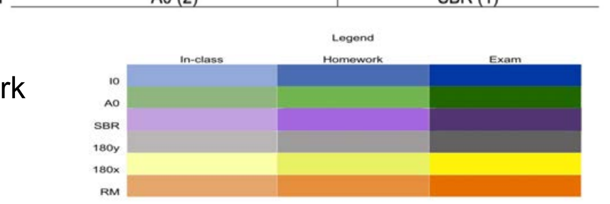
	Most practiced rotations
In-class	A0, SBR (10 each)
HW	A0, SBR, 180y, RM (2 each)
Exam	A0, SBR (3 each)

Class 4

	Most practiced rotation	Second practiced rotation
In-class	N/A	N/A
HW	A0 (7)	SBR, RM (3 each)
Exam	A0 (2)	SBR (1)

Figure 2 . Modified sunburst visualizations demonstrating the progression of mental rotations required in problems from in-class materials, homework assignments, and exams

The most practiced rotations across the four classes are listed below with the number of problems featuring that action in parentheses



RESULTS ON CODING AND REPRESENTATION TYPES

Coding Scheme

I0	0 degree rotation–whole molecule. All groups are aligned indicating that the compounds are superimposable/identical in their current orientation.
A0	0 degree rotation–whole molecule. Two groups are superimposable while two groups are not, indicating that the compounds are not superimposable without further movement required.
SBR	109.5 degree rotation–atoms. When the backbone of both molecules are aligned, but the atoms in the dash, wedge, or plane positions are not matched and must be rotated around the single bond in order to check for superimposability or mirror.
180Y	180 degree rotation–whole molecule. Need to flip entire molecule 180 degrees across the y-axis (side by side) to line up backbone.
180X	180 degree rotation–whole molecule. Need to flip the entire molecule 180 degrees across the x-axis (top to bottom or bottom to top) to line up backbone.
RM	Rotation of molecule that can be greater or less than 180 degrees

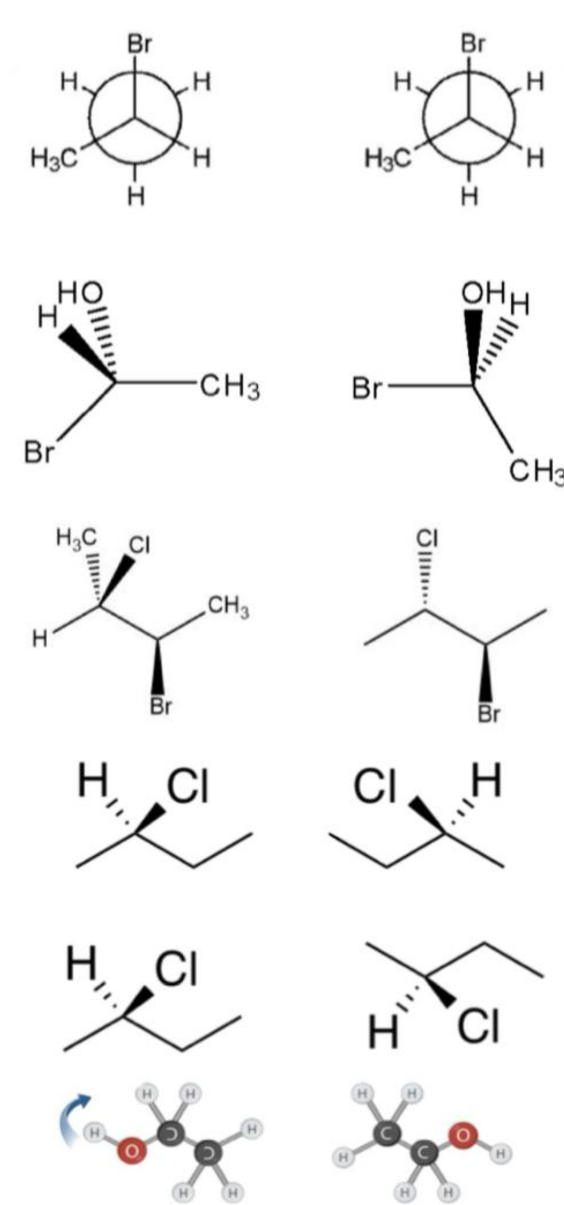
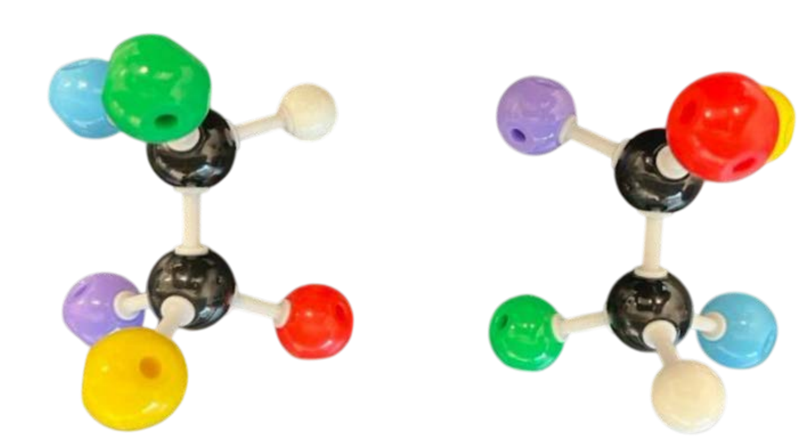
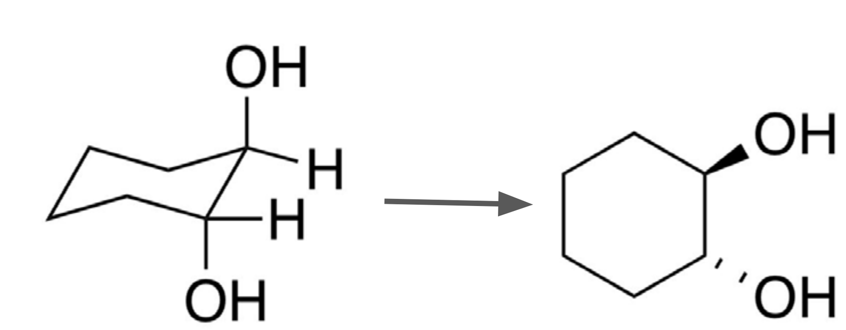


Figure 3. Table above descriptions for created code for identified movements





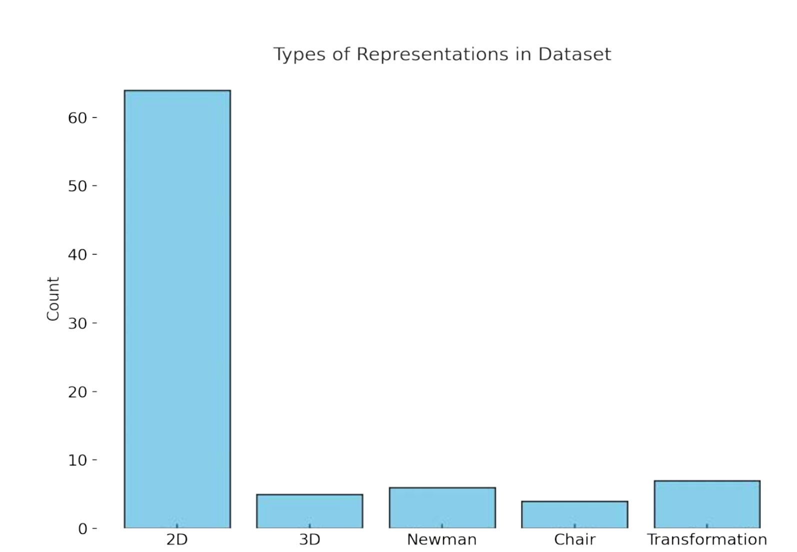


Figure 4. Distribution of representation types in the dataset

DISCUSSION

- 2D representations dominate the database. Highlighting a strong emphasis on 2D visualization in the materials.
- Our analysis revealed a prevalence of the A0 code, indicating that the molecules are already aligned without requiring further movement during problem solving. This does not guarantee that a student will not do further movements.
- This finding contrasts with our initial expectations, where organic chemistry problems were hypothesized to require at least one movement.
- Single-bond rotations are the second most common movements required, yet such rotations are unique to organic molecules. More information is needed on how people perform this kind of movement.

CONCLUSIONS

- Results highlight the need to re-evaluate how visualization and spatial reasoning are integrated into organic chemistry education.
- The lack of required movement suggests that problems focus on analyzing the relationships between molecules, rather than rotating them, but students could encounter high cognitive load in trying to make them superimpose.

FUTURE DIRECTIONS

- Assessing students with current coding schemes to understand their visualization routes.
- Find ways to scaffold mental rotation tasks unique to organic chemistry to allow student to develop visualization skills necessary for success.
- Examine use of model kits and discern how students specifically rotate models of molecules. Determine how use of model kits align with mental rotation movements.

REFERENCES

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2. Salame, Issa I., and Sheikh Aleena Kabir. 2022. "Examining Students' Spatial Ability and Its Impact on the Learning of Stereochemistry." *Interdisciplinary Journal of Environmental and Science Education* 18 (4): e2288. https://doi.org/10.21601/ijese/12099.