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The Iceberg Phenomenon - What does Research tell us about Teaching (Chemistry)?

Institute of Chemistry Education

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Agenda

Insights into cognitive psychology

Task design

Multimedia design and visual guidance

(Conceptual guidance)

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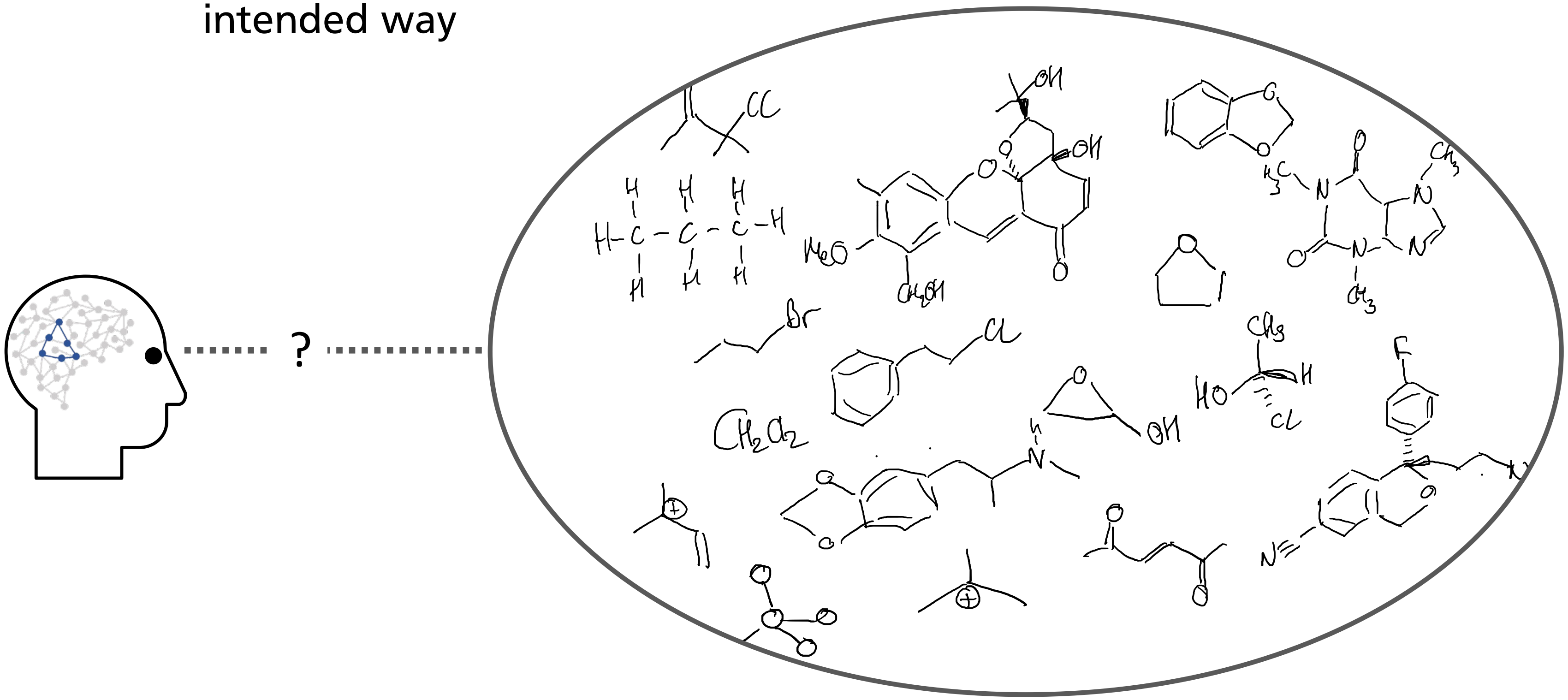
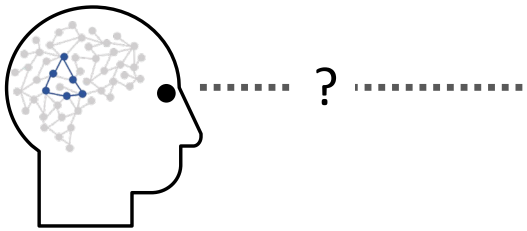
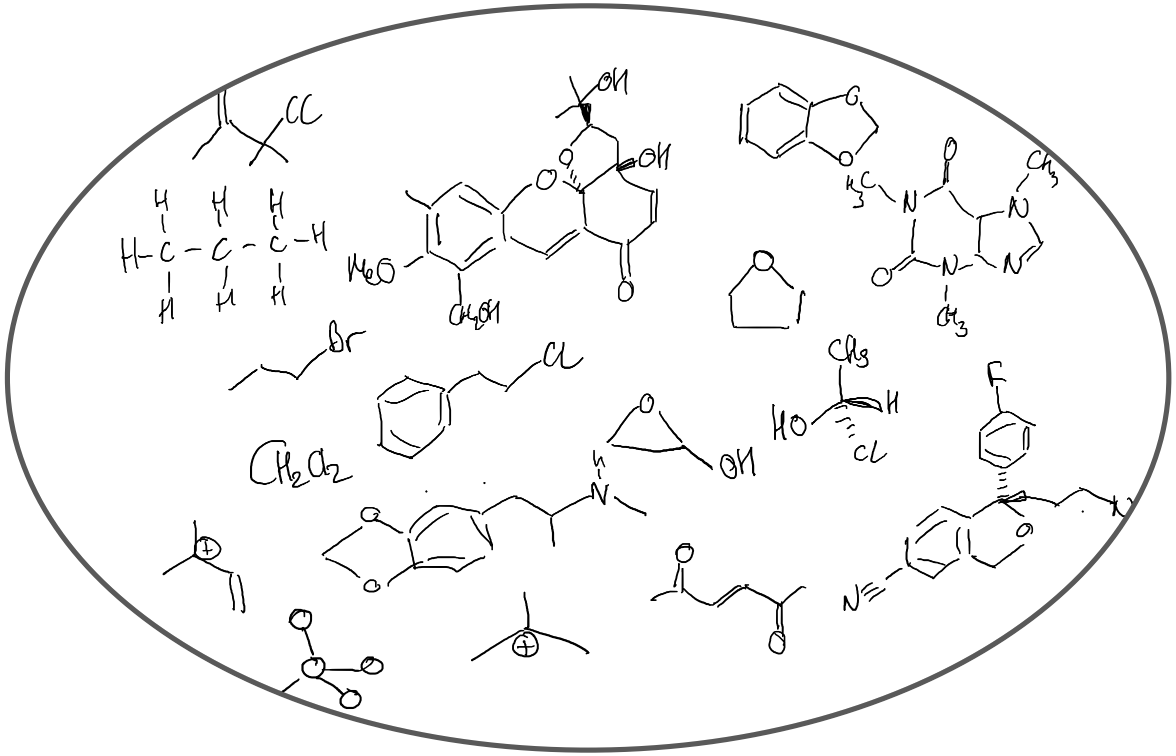
Students are often **not** perceiving representations in chemistry in the intended way



Students are often **not** perceiving representations in chemistry in the intended way

Why should they?





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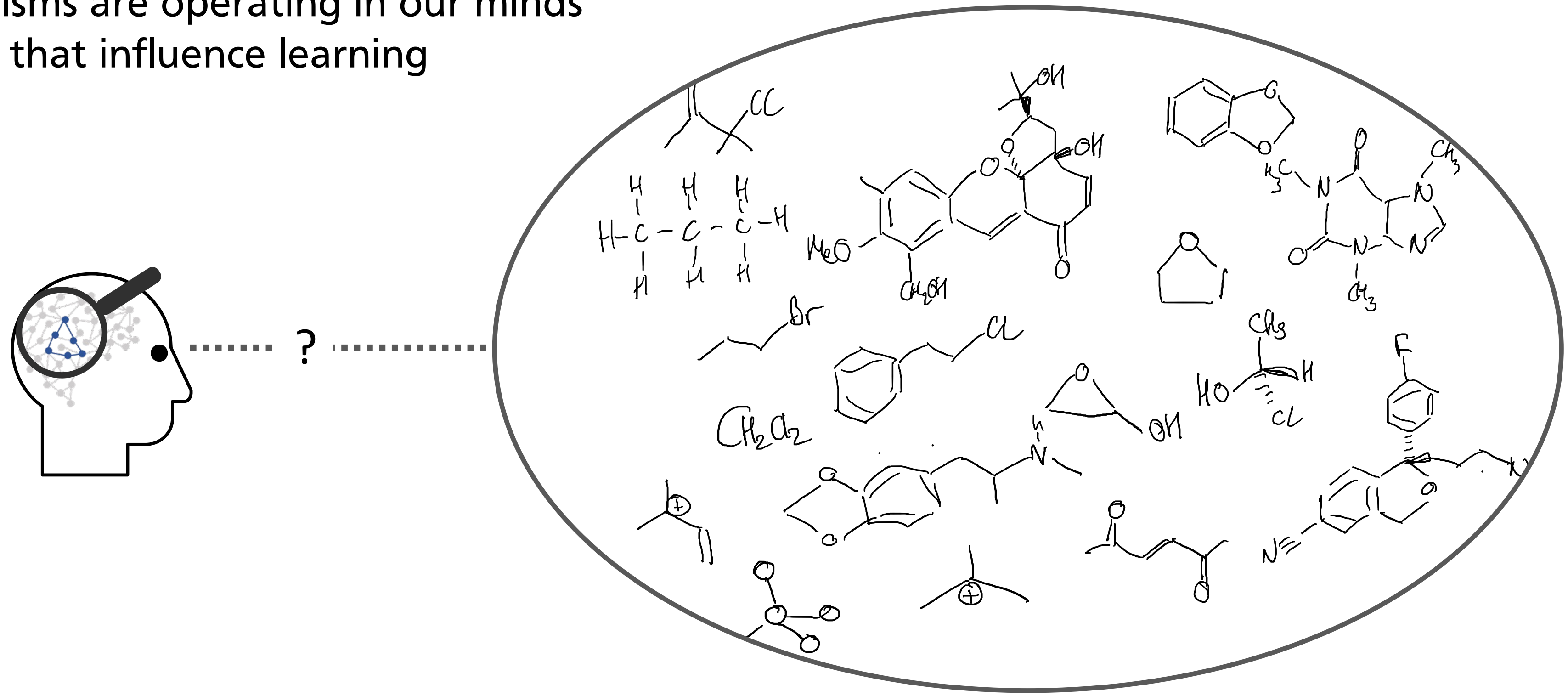
Various information-processing mechanisms are operating in our minds that influence learning



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People operate within the constraints imposed by both their cognitive resources and the task environment.

Bounded Rationality

Simon, H. A. (1955). A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics, 69*(1), 99-118.

Does the letter ‘k’ occur most often at the beginning or in the middle of a word?

Tversky & Kahneman, **1973** Availability: A Heuristic for Judging Frequency and Probability. *Cogn. Psychol.* 5, 207–232.

Kayak
K in first position

anKle
K in the middle

Does the letter ‘k’ occur most often at the beginning or in the middle of a word?

Tversky & Kahneman, **1973** Availability: A Heuristic for Judging Frequency and Probability. *Cogn. Psychol.* 5, 207–232.

Kayak	anKle
K in first position	K in the middle
70%	30%

What would you think is more likely to kill you?

Barass **1984** *The Journal of Trauma* 24(11):990-1.

A

B

Picture references: https://www.nzz.ch/wissenschaft/megalodon-neue-analyse-zu-koerpermassen-des-gigantischen-hais-ld.1577863; https://www.flickr.com/photos/30478819@N08/49590476857

What would you think is more likely to kill you?

Barass **1984** *The Journal of Trauma* 24(11):990-1.

A

B

We reason economically
– We favor simple-looking options over complex ones

Picture references: https://www.nzz.ch/wissenschaft/megalodon-neue-analyse-zu-koerpermassen-des-gigantischen-hais-ld.1577863; https://www.flickr.com/photos/30478819@N08/49590476857

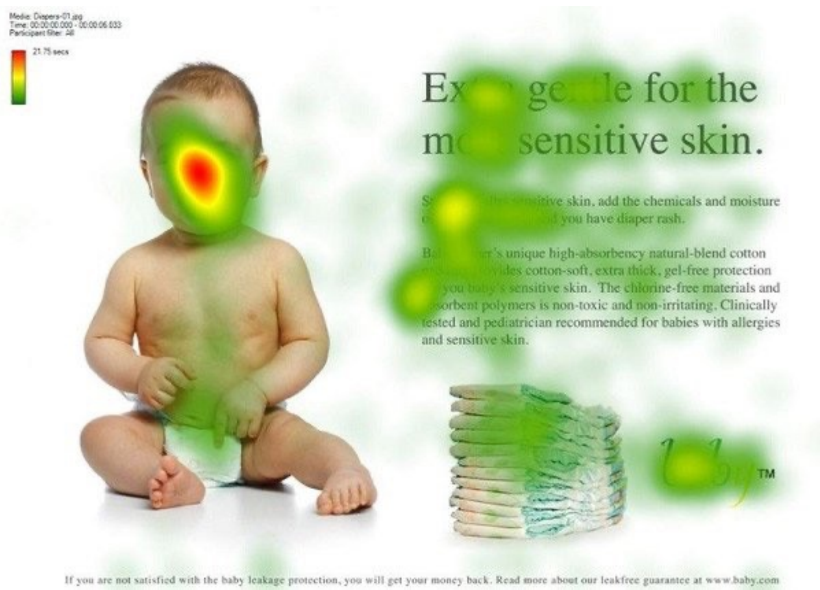
Which one would you choose in a supermarket?

Simon **1955** A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics, 69*(1), 99-118.

Cheap Good Expensive

HOW DOES OUR MIND FUNCTION?

We visually attend to immediate and relatable features.



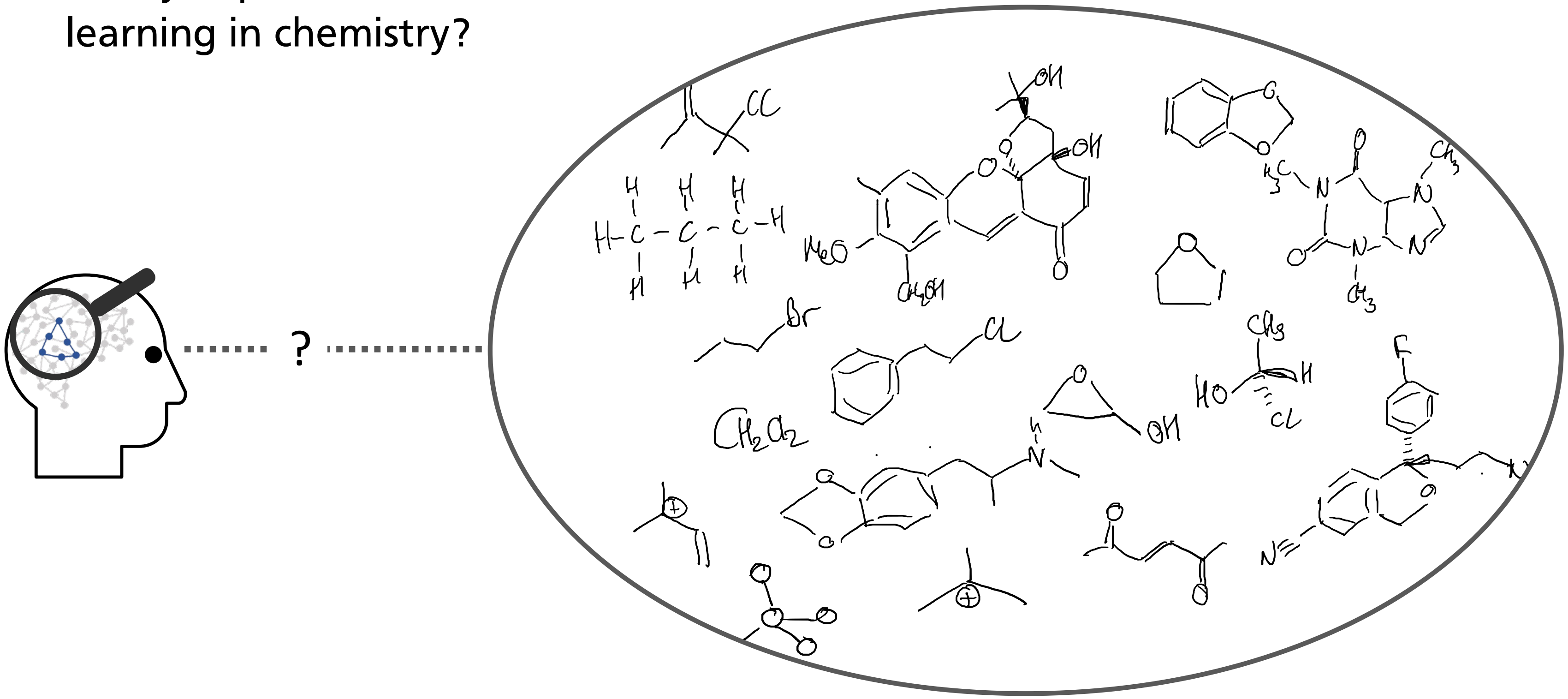
Picture reference: https://neilpatel.com/blog/eye-tracking-studies/

How does our mind function?

We visually attend to immediate and relatable features.

Picture reference: https://neilpatel.com/blog/eye-tracking-studies/

To what extend could this actually impact students' learning in chemistry?

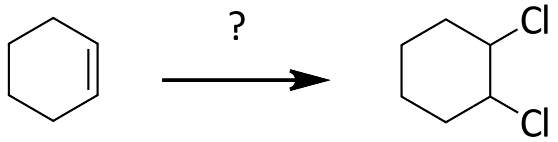


The more is more strategy

Graulich N. **2015** Intuitive Judgments Govern Students' Answering Patterns in Multiple-Choice Exercises in Organic Chemistry, **JCE** 92, 205-211.

Which are the appropriate reagents for this reaction?

Attribute substitution effect



a.) HCl, CH_2Cl_2

b.) HCl, H_2O

c.) Cl_2, H_2O

d.) Cl_2, CH_2Cl_2

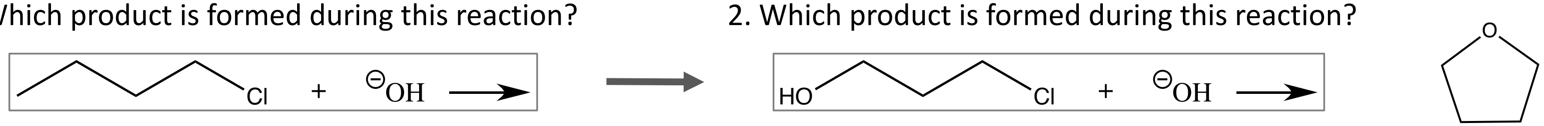
Hanna: *"I would go with d.) There are two chlorines in the product, so with Cl_2 and CH_2Cl_2, I guess, you have enough chlorines to make it."*

Knowledge pieces that are more familiar are more likely activated and used

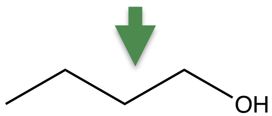
Lieber & Graulich **2020** Thinking in Alternatives—A Task Design for Challenging Students' Problem-Solving Approaches in Organic Chemistry. *JCE* 97(10), 3731-3738.

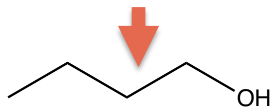
1. Which product is formed during this reaction?

2. Which product is formed during this reaction?



Haley's solution:



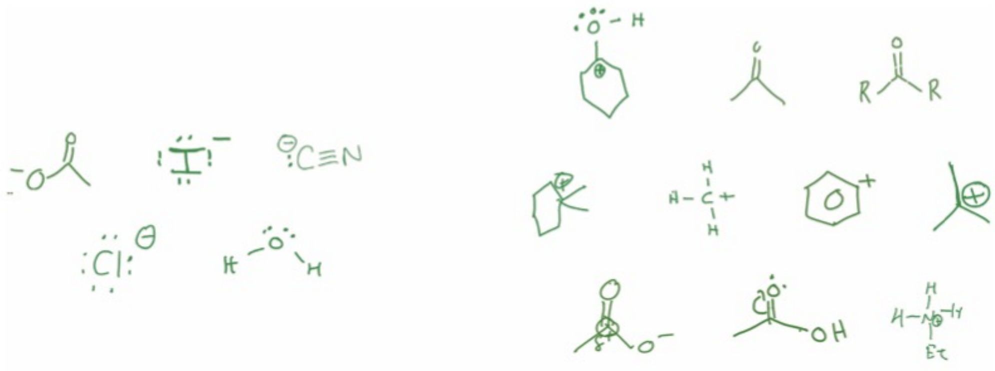


"It was more like an automatism that I used. Somehow, I saw the reaction and reagents before. That's how I do it. I don't think about how they behave and so on. It's more like "shoot from the hip" as the phrase goes."

STUDENT PROBLEM-SOLVING IN CHEMISTRY

„Students are engaged in rote memorization of what features are related to nucleophilic and electrophilic behavior, rather than try to more deeply comprehend the relationships between those features and functionality.“

Anzovino & Bretz **2015** Organic chemistry students' ideas about nucleophiles and electrophiles: the role of charges and mechanisms, *CERP 16*, 797–810.



(a) (b)

Fig. 3 Student examples of (a) nucleophiles and (b) electrophiles.

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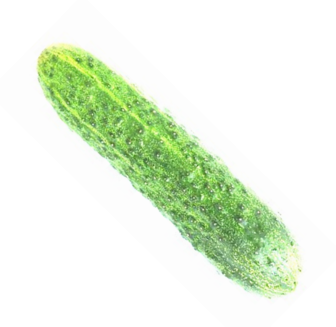
Decisions based on salience are easier than attending to implicit information

Which two food items are more similar?

A

B

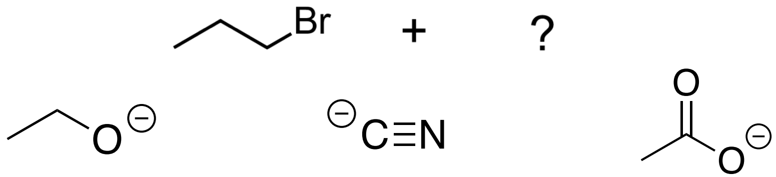


C

Decisions based on salience are easier than attending to implicit information

Graulich, Hedtrich & Harzenetter **2019** Explicit versus implicit similarity – exploring relational conceptual understanding in organic chemistry. *CERP 20*(4), 924-936.

Decide which two nucleophiles would react similar in a substitution reaction with the bromalkane.



A **B** **C**

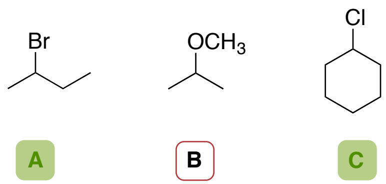
Cameron: *A and C are good nucleophile, both have negatively charged oxygens*

Assessing students’ ability to attend to implicit similarity

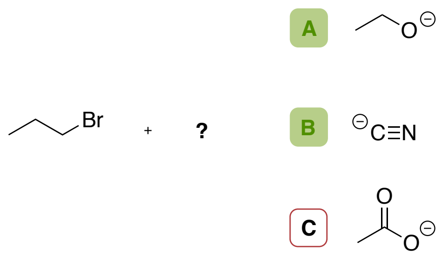
Graulich, Hedtrich & Harzenetter **2019** Explicit versus implicit similarity – exploring relational conceptual understanding in organic chemistry. *CERP 20* (4), 924-936.

Decide which two molecules would react similar in a substitution reaction.

Leaving group



Nucleophilicity



Item type 1 - supporting

Explicit features support the solution

Item type 2 - distracting

Explicit features do NOT support the solution

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Assessing students' ability to attend to implicit similarity

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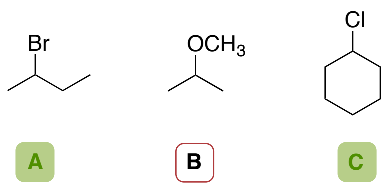
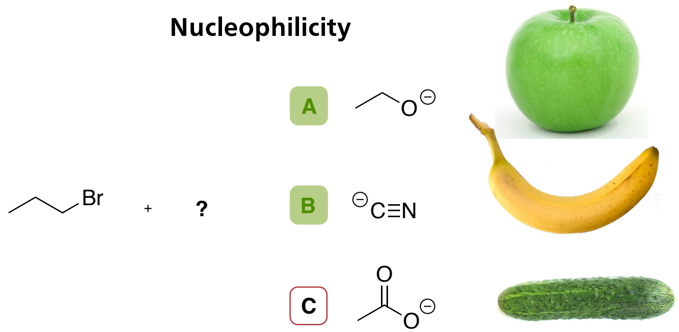


Nucleophilicity



Item type 1 - supporting

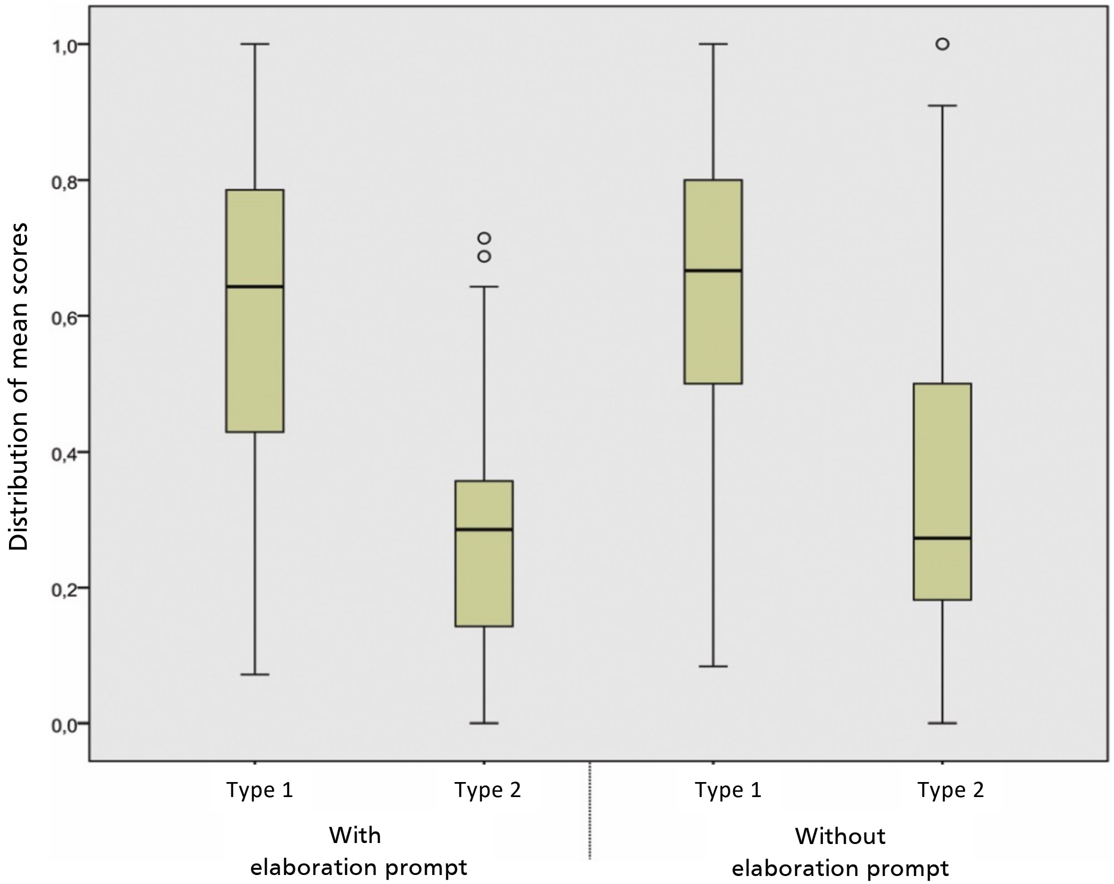
Explicit features support the solution

Item type 2 - distracting

Explicit features do NOT support the solution

STUDENT PROBLEM-SOLVING IN CHEMISTRY

- Large effect sizes for the item types (Cohen's d=1.4)
- A rather small effect size for the request for justification in both item types (type 2: d=0.31, p=0001; type 1: d=0.26, p= 0.009)

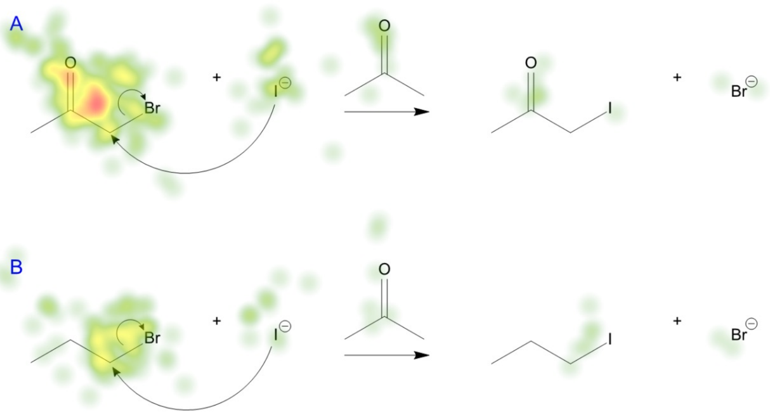


Itemtyp 1
supportive

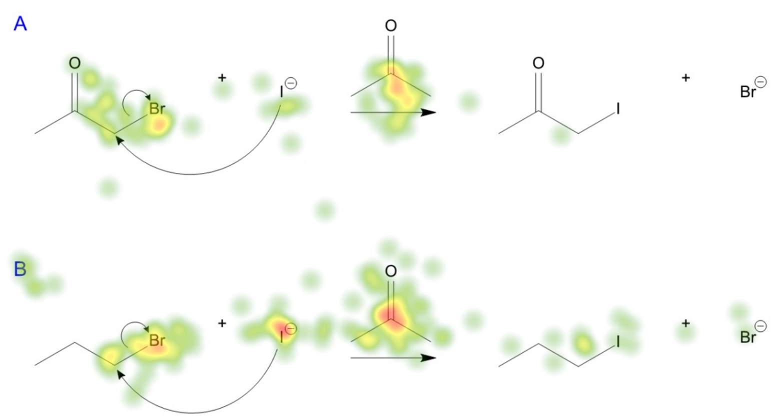
Itemtyp 2
distracting

Different expertise is evident in different eye-movements

Rodemer, Eckhard, Graulich & Bernholt **2020** Decoding Case Comparisons in Organic Chemistry: Eye-Tracking Students' Visual Behavior. JCE 97(10), 3530-3539.



Successful problem-solver



Un-successful problem-solver

STUDENT PROBLEM-SOLVING IN CHEMISTRY

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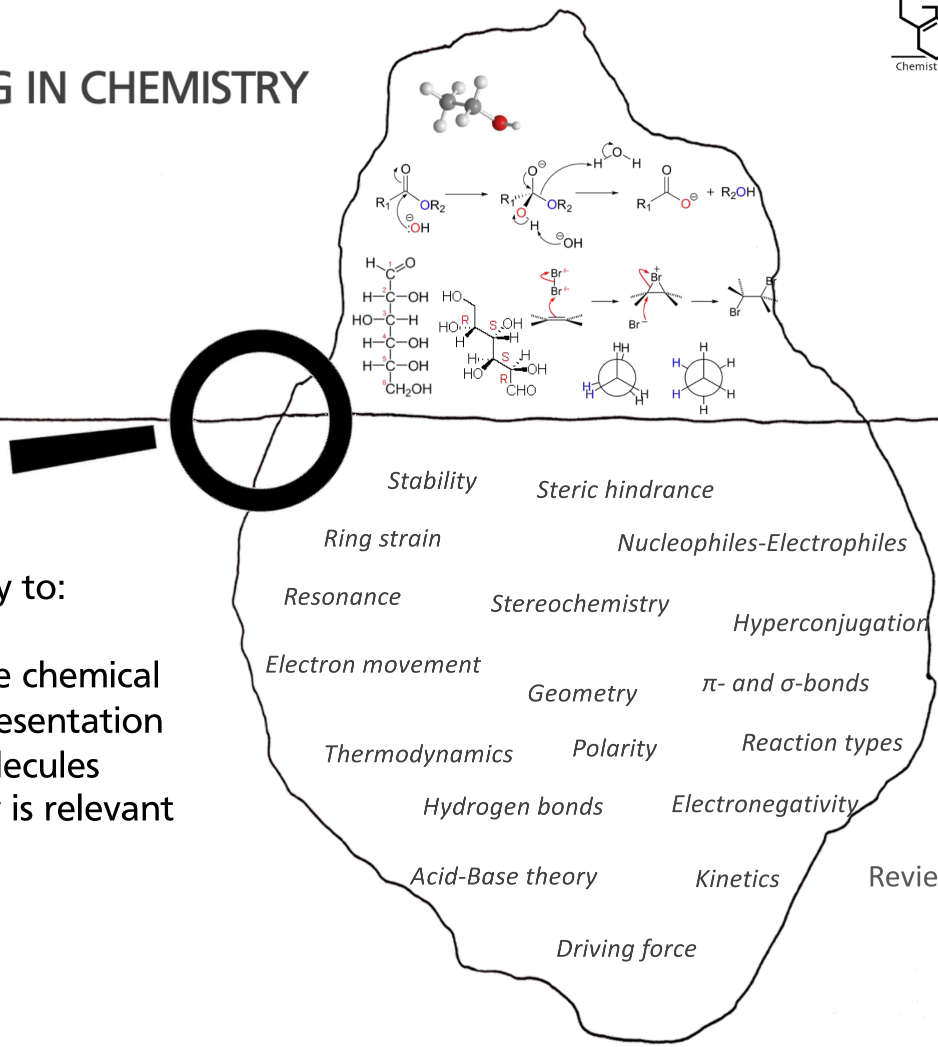
students' success depends on the ability to:

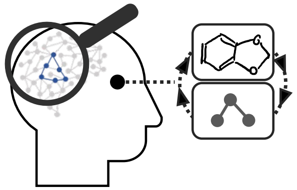
(1) establish connections between the chemical properties and the structural representation
(2) consider implicit properties of molecules
(3) determine which implicit property is relevant in a problem context



Review: Graulich, **2015**, *Chem. Educ. Res. Pract.*, *16*, 9-21.

Cognitive Perspective on Learning

What can we do to fit environment (instruction) and the mind (learner) together?



1 Task Design

2 Visual Guidance

3 Conceptual Guidance

How to know what to attend to?

Graulich & Schween **2018** Concept-Oriented Task Design: Making Purposeful Case Comparisons in Organic Chemistry. *JCE 95* (3), 376-383.

Task Design

Learning through comparing cases that differ in purposefully chosen variables.

Bransford & Schwartz 1999, Review of Research in Education, 24 1999, 24, 61-100.

- „Inventing“ concepts with contrasting cases is more effective for subsequent learning than „Tell-and-Practice“ (Schwartz et al. 2011, J. Educ. Psychol.)
- Comparing and contrasting problem-solving strategies of others does improve student procedural knowledge (Star & Rittle-Johnson, 2009, 2007, J. Educ. Psychol.)

TASK DESIGN – CONTRASTS-TO-LEARN

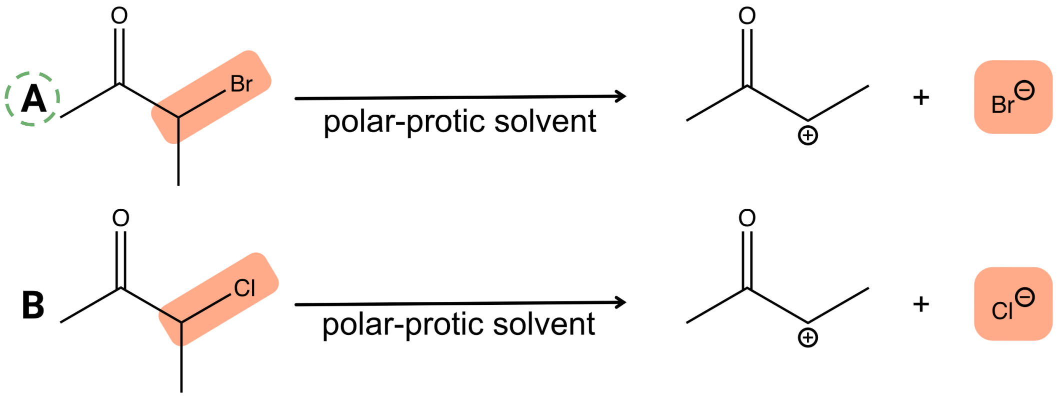
Highlighting on one/two variables to focus learning

Graulich & Schween **2018** Concept-Oriented Task Design: Making Purposeful Case Comparisons in Organic Chemistry. *JCE 95*(3), 376-383; Kranz, Schween & Graulich **2023** Patterns of reasoning – exploring the interplay of students' work with a scaffold and their conceptual knowledge in organic chemistry, CERP 24(2), 453-477.

Explain which of the two reaction steps proceeds faster.

Contrasting case

1 variable



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Highlighting on one/two variables to focus learning

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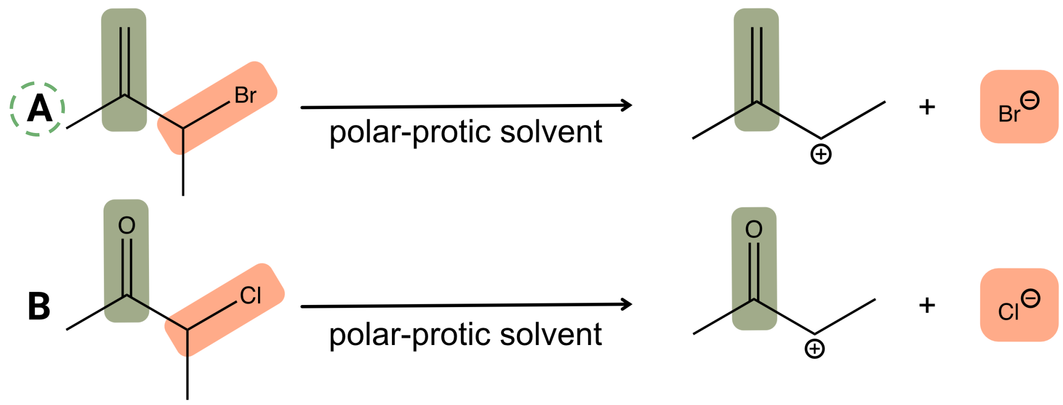
Explain which of the two reaction steps proceeds faster.

Contrasting case

2 variables



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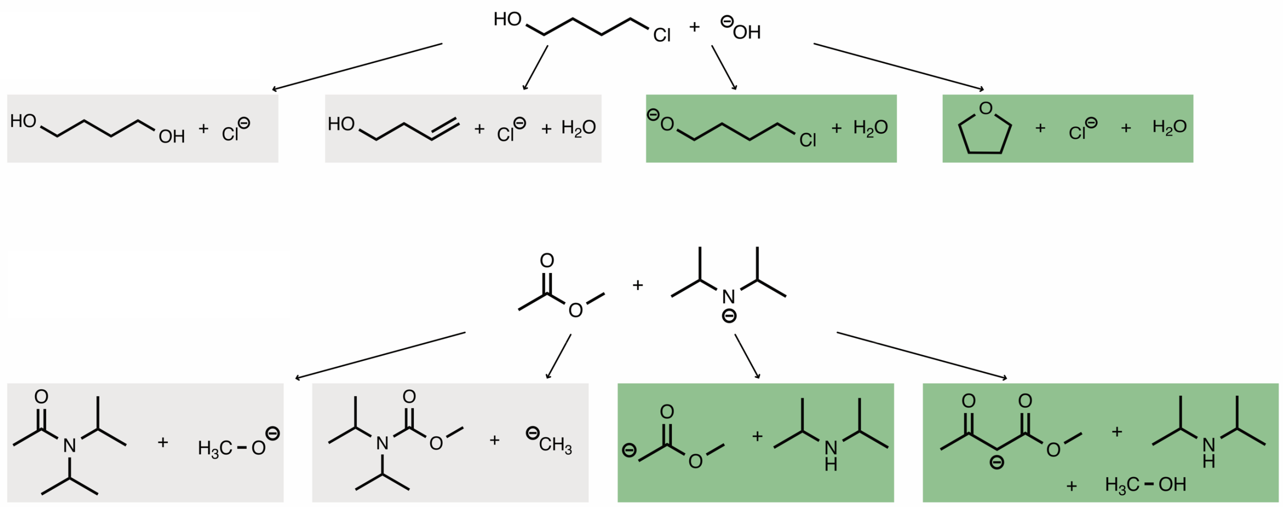
Engaging student in reasoning by comparing

Lieber & Graulich **2020** Thinking in Alternatives—A Task Design for Challenging Students' Problem-Solving Approaches in Organic Chemistry. *JCE 97*(10), 3731-3738.



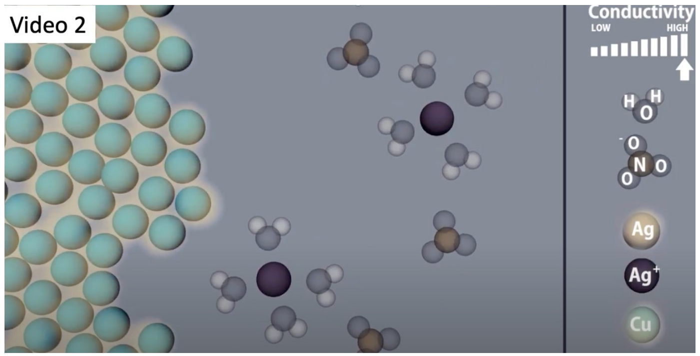
Prompt:
Here are various peer-solutions. Describe how you think these students came to this solution. What do you think was their underlying reasoning?

TASK DESIGN – CONTRASTS-TO-LEARN

Critically evaluating supports students to see and argue about differences

Hansen et al. 2019 Critical consumption of chemistry visuals: eye tracking structured variation and visual feedback of redox and precipitation reactions. *CERP 20*(4), 837-850.

Reaction of a cooper wire in silver nitrate solution on the submicroscopic level



Task Design – Contrasts-to-learn

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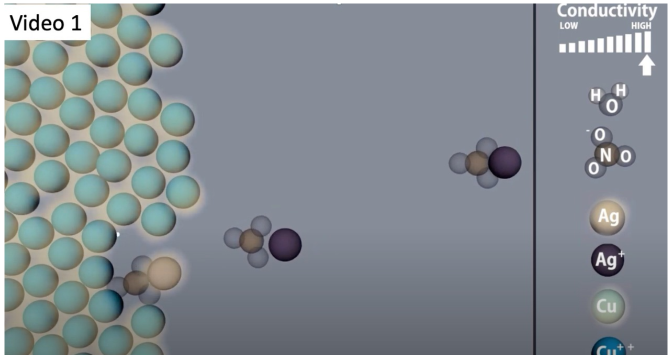

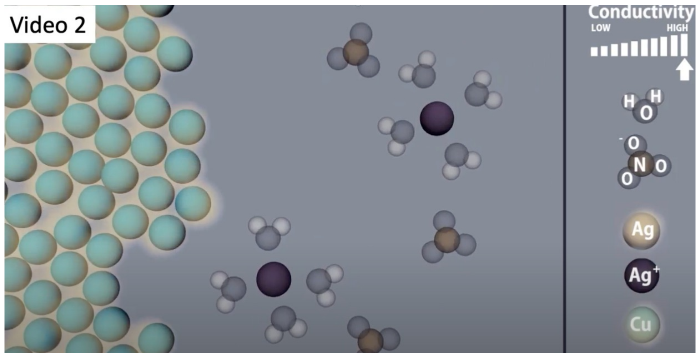

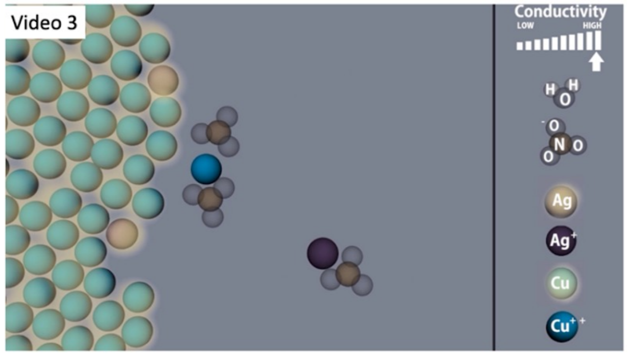

Task Design – Contrasts-to-learn

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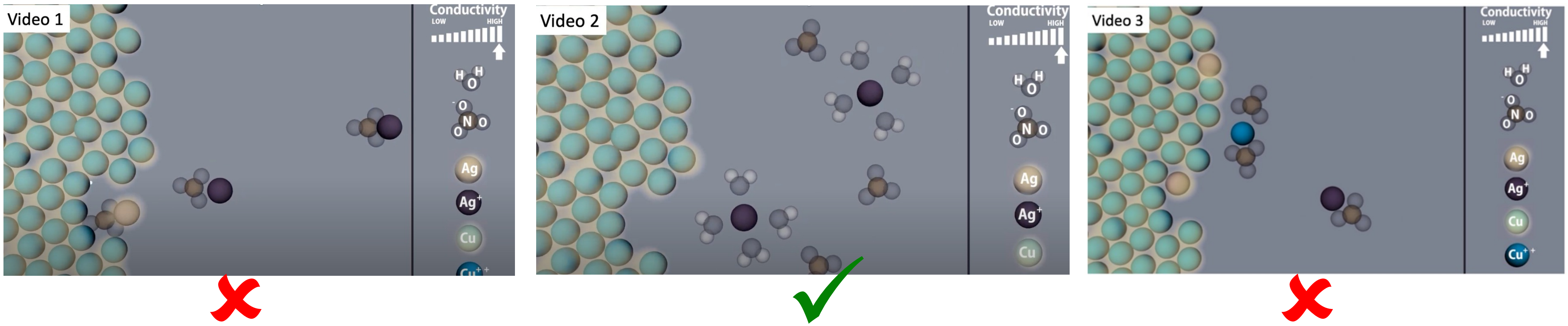
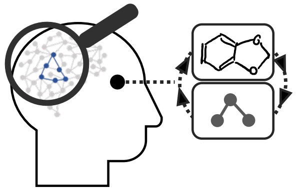


COGNITIVE PERSPECTIVE ON LEARNING

What can we do to fit environment (instruction) and the mind (learner) together?



1 Task Design

- Reasoning is economic (we choose the most accessible information).
- Purposeful task design allows to emphasize critical features for learning and assessment.

2 Visual Guidance

3 Conceptual Guidance


Hauptbahnhof
Straße
Achtung Baus
Torstraße
Staugefahr
30
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Hauptbahnhof
Straße
Achtung Baus
Torstraße
Staugefahr
30
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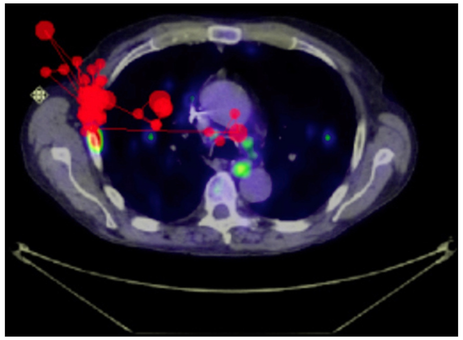
Only 30 km/h are allowed

VISUAL GUIDANCE - SUPPORTING LEARNERS' ATTENTION

- Cueing upon relevant aspects of the representation can reduce cognitive load (Lowe & Schnotz 2014, Richter *et al.* Educ. Res. Rev. 2016, Schneider *et al.* Educ. Res. Rev. 2018)
- Connecting the explicit feature of a representation with the corresponding explanation (Mayer, Multimedia learning, 2014; Van Gog & Rummel Educ. Psychol. Rev. 2010)
- Using an experts' eye gaze or cueing techniques to guide learners' attention in perceptual tasks (Gegenfurtner *et al.* Comp. Educ. 2017; Hyönä Learn. Instruct. 2010; Jarodzka *et al.* Learn. Instruct. 2013)



Gegenfurtner *et al.* Comp. Educ. 2017.

Jarodzka *et al.* Learn. Instruct. 2013.

DESIGNING INSTRUCTIONAL VIDEOS

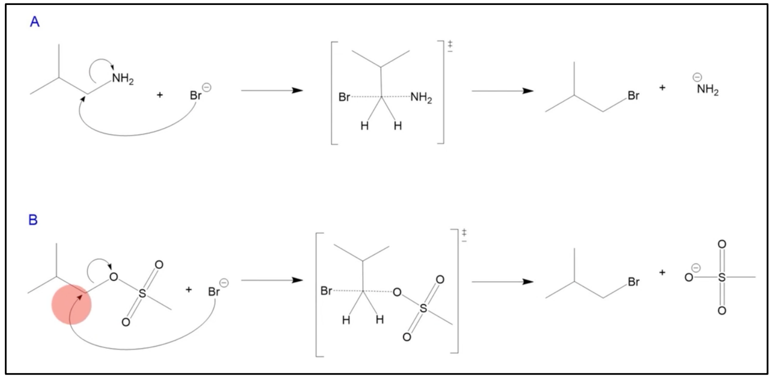
Linking visual cueing and verbal explanations in tutorial videos

Rodemer, Eckhard, Graulich & Bernholt **2021** *Int. J. Sci. Educ.*, 1-22.

Jarodzka *et al.* Learn. Instruct. 2013.

Others: Boucheix & Lowe, Learn. Instruct. 2010; De Koning et al. Learn. Instruct. 2010.

Dynamic cueing



Structure of the verbal explanation

Explicit structural difference

Influence — Cause → Effect

Change

VISUAL

Processing

CONCEPTUAL

Processing

Instructional videos

guided by principles of multimedia learning
in order to support mechanistic reasoning in organic chemistry

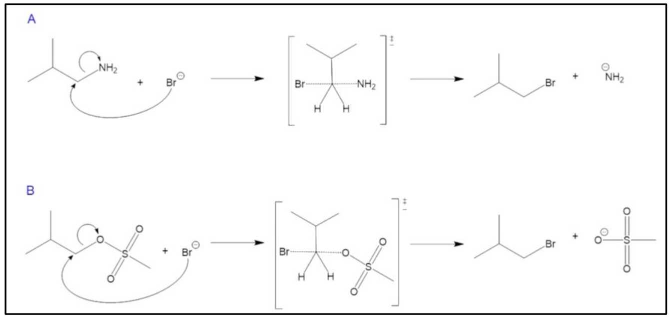
within the scope of the bachelor thesis of Anna Fotidis

EFFECTS OF VISUAL GUIDANCE IN INSTRUCTIONAL VIDEOS

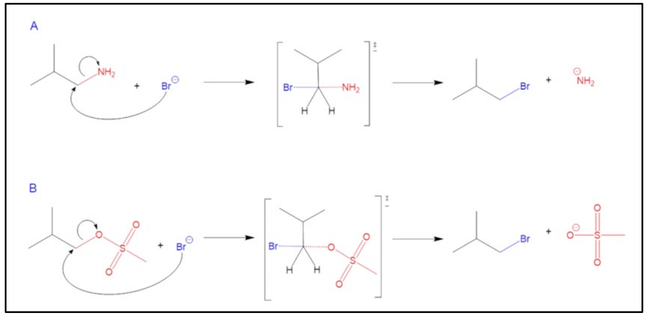
Research Question:

Does cueing on relevant features of a representation improve learners' conceptual understanding more than one tutorial video with static (color) cueing and more than one without cuing?

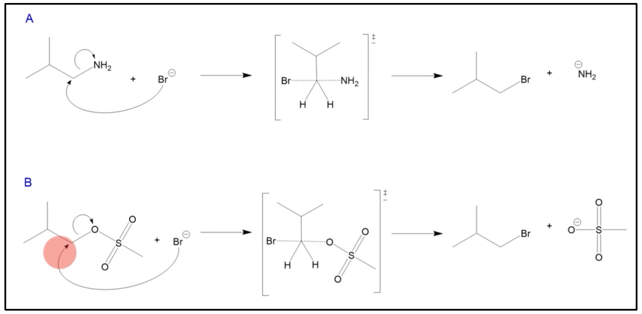
No cueing



Static color cueing

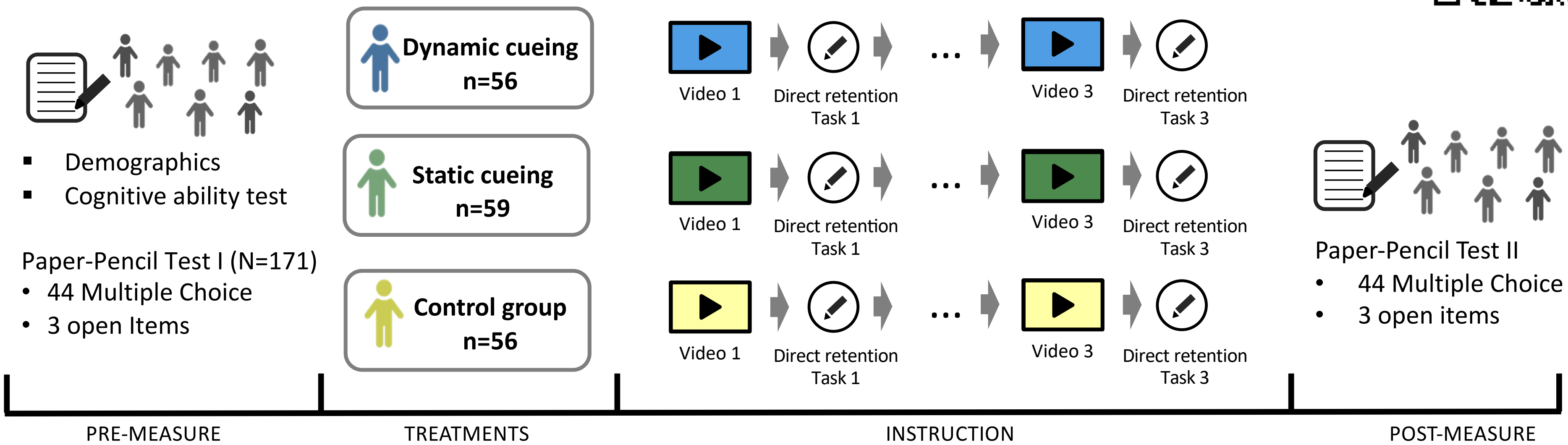


Dynamic cueing



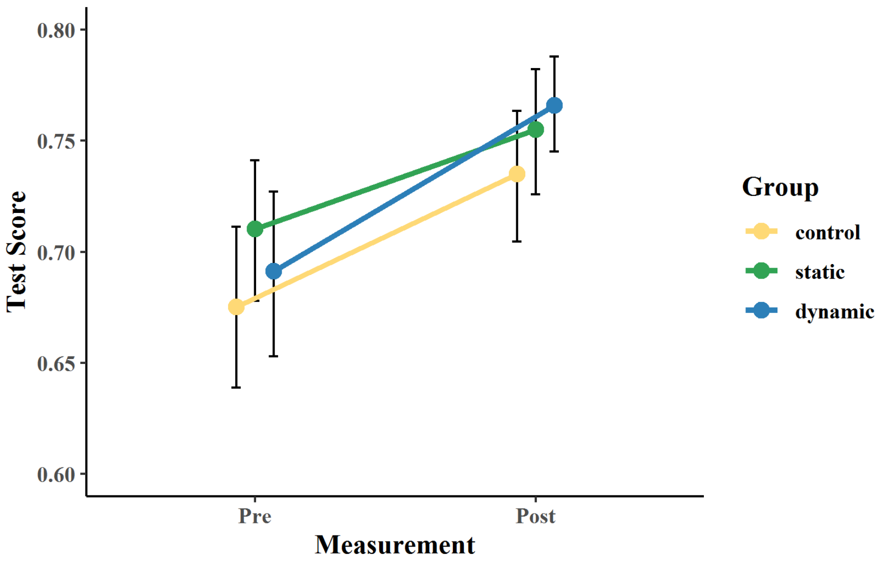
Study Design

Randomized control trial



RESULTS

Treatment effects on students' knowledge gains



Repeated measures ANOVA:
No significant difference in pre- and post scores

$F_t = 35.83, F_{crit} = 4.01, p < .05, \hat{\psi} = -0.06\ [-0.08, -0.04]$
Errors bars 95% confidence interval

- pretest and posttest score did not differ significantly between the groups.
- all treatment groups seem to benefit significantly from the tutorial videos ($p < .05$)

Results – Direct Comprehension

Treatment effects on students' direct retention task

- Coding students' answers after each video (Cohen's κ = .79)

Quality of the explanation

3. Emergent cause-effect relations

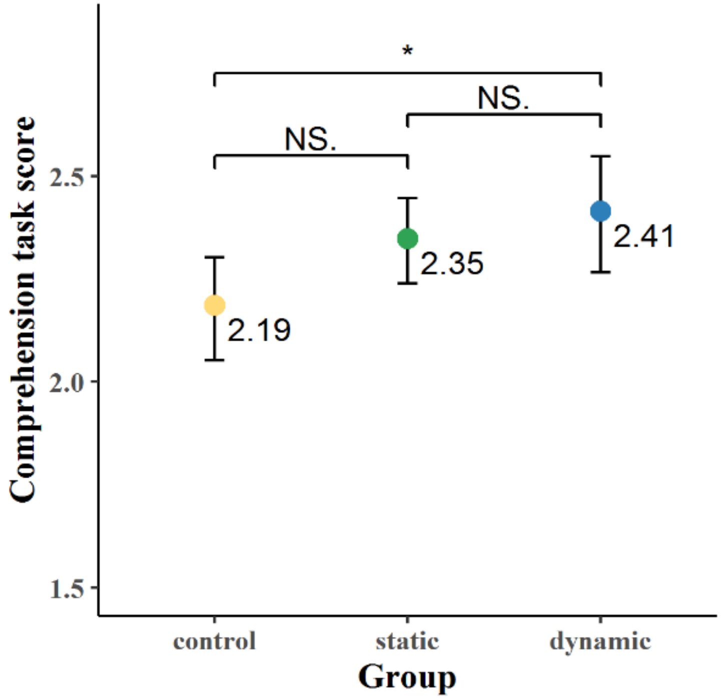
"The mesylate ion can distribute electrons with resonance structures across multiple atoms, so the negative charge is delocalized in the process."

2. Implicit Properties

„The mesylate ion can form resonance structures"

1. Difference in function and/or stability

„The mesylate ion is a stable leaving group."

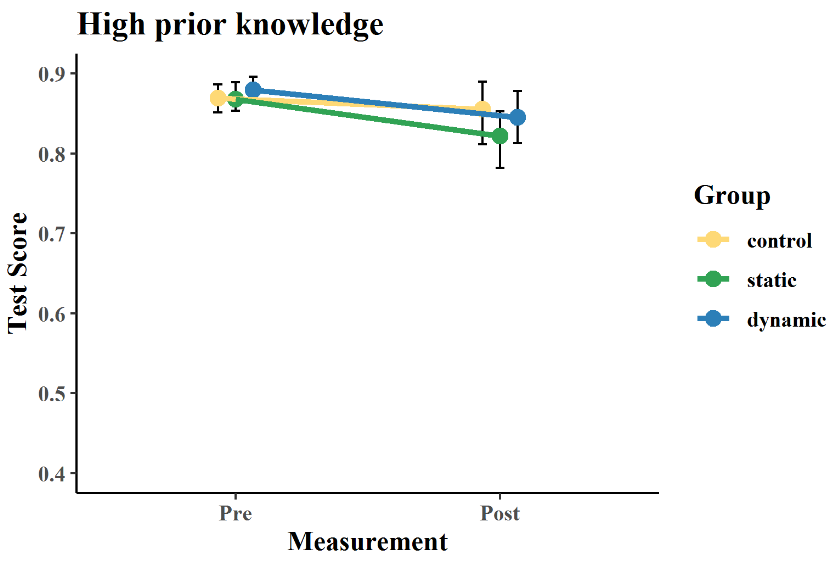


ANOVA:
$F(2,168) = 3.24$, $p = .041$, $\eta^2 = .04$.

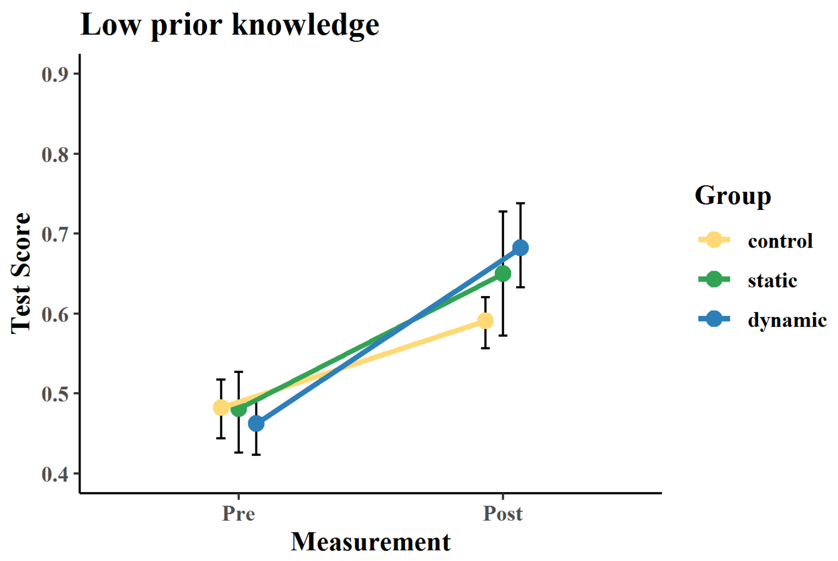
Rodemer, Eckhard, Graulich & Bernholt **2021** *Int. J. Sci. Educ.*, 1-22.

RESULTS

Treatment effects with regard to students' prior knowledge



ANOVA:
$F(2,30) = 0.80$, $p = .457$, $\eta^2 = .051$
Errors bars 95% confidence interval

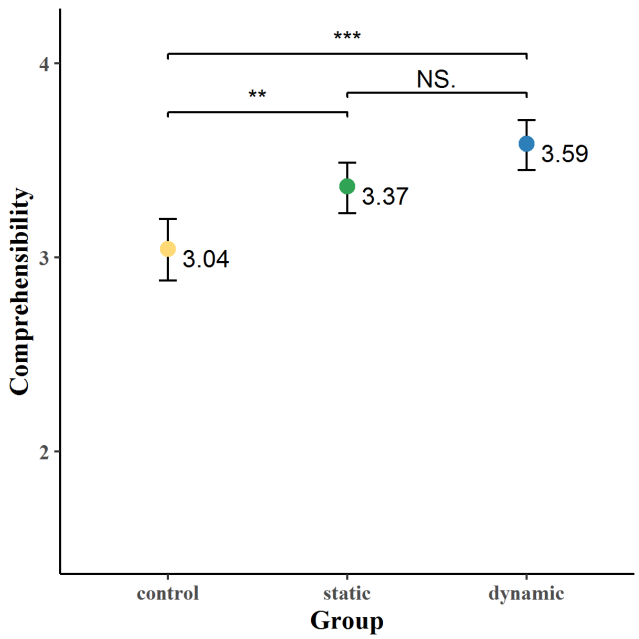


ANOVA:
$F(2,26) = 3.59$, $p = .042$, $\eta^2 = .216$
Errors bars 95% confidence interval

Rodemer, Eckhard, Graulich & Bernholt **2021** *Int. J. Sci. Educ.*, 1-22.

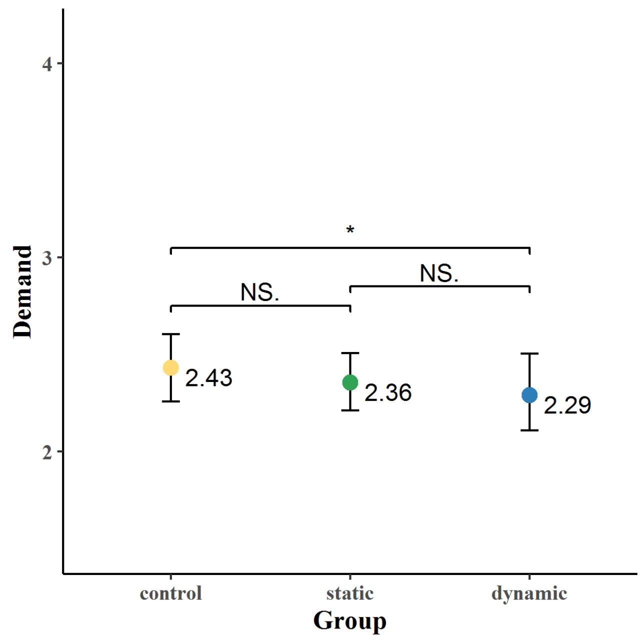
Students' perception of the tutorial videos

- 4 items 4-point Likert scale for each scale



Comprehensibility

ANOVA: $F(2,168) = 15.03$, $p < .001$, $\eta^2 = .15$

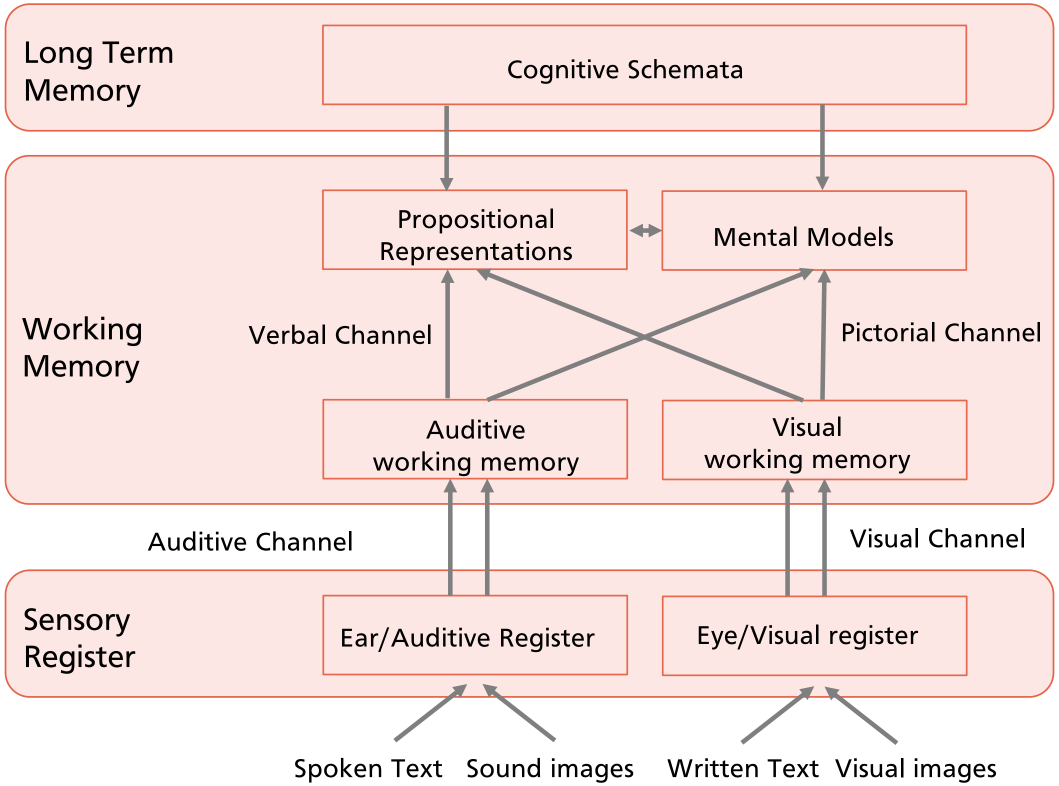


Demand

ANOVA: $F(2,167) = 3.69$, $p = .027$, $\eta^2 = .042$

Rodemer, Eckhard, Graulich & Bernholt **2021** *Int. J. Sci. Educ.*, 1-22.

INTEGRATED MODEL OF TEXT AND PICTURE COMPREHENSION



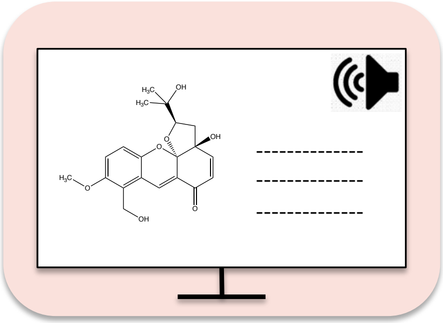
Influence of prior knowledge on selecting, organizing and integration of information

Serving both channels:
People learn better from graphics (visual channel) with spoken text (auditive channel) rather than graphics with printed text.

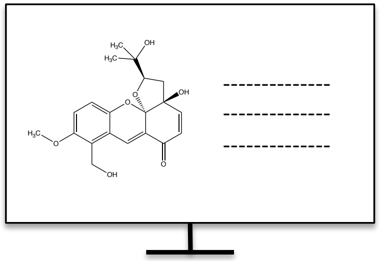
Schnotz W. (2005) An Integrated Model of Text and Picture Comprehension, in *The Cambridge Handbook of Multimedia Learning*, New York, NY, US: Cambridge University Press, pp. 49-69.

Designing videos for teaching

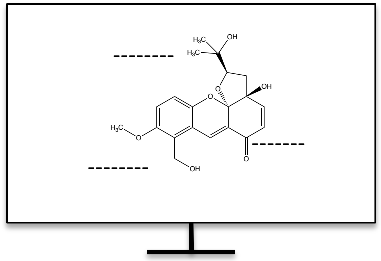
Keep it simple!

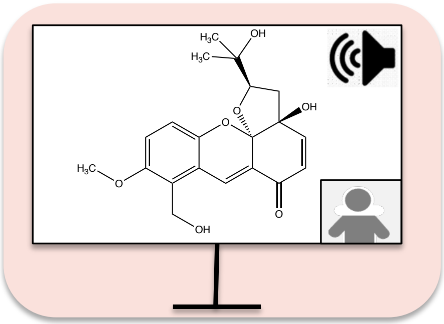


Only one - **Coherence principle**

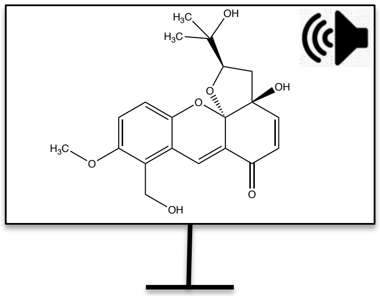


Even better – **spatial contiguity principle**

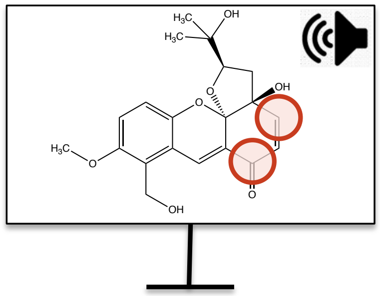




Only one - **Coherence principle**



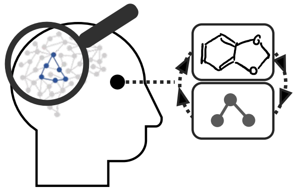
Even better - **Signaling principle**



Mayer R. E. (2005) Cognitive theory of multimedia learning, in *The Cambridge handbook of multimedia learning*, ed. Mayer R. E., New York: Cambridge University Press, pp. 31-48.

COGNITIVE PERSPECTIVE ON LEARNING

What can we do to fit environment (instruction) and the mind (learner) together?



1 Task Design

- Reasoning is economic (choosing the most accessible information).
- Purposeful task design emphasizes critical features

2 Visual Guidance

- Digital instructional tools, such as cueing guide students' attentional focus
- Low prior knowledge students profit from cueing techniques

3 Conceptual Guidance

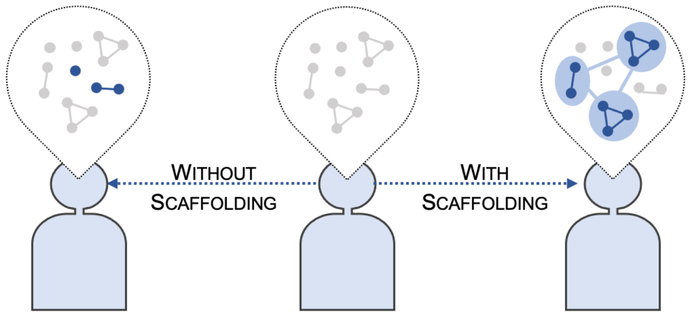
Conceptual Guidance

Scaffolding is a

"process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts."

Wood, D.; Bruner, J. S.; Ross, G. (1976) The Role of Tutoring in Problem Solving. J. Child Psychol. Psychiatry, 17 (2), 89–100.

Graulich, N.; Langner, A.; Vo, K. & Yuriev, E. (2021). Scaffolding Metacognition and Resource Activation During Problem Solving: A Continuum Perspective. In G. Tsaparlis (Ed.), *Problem-Solving in Chemistry*. Cambridge: Royal Society of Chemistry.



(1) Structuring the task
(2) Activation of cognitive resources
(3) Making important connections visible

Conceptual Guidance

Goal:

Slowing down the problem-solving process, avoiding one-reason decision making

Graulich, N.; Langner, A.; Vo, K. & Yuriev, E. (2021). Scaffolding Metacognition and Resource Activation During Problem Solving: A Continuum Perspective. In G. Tsaparlis (Ed.), *Problem-Solving in Chemistry*. Cambridge: RSC.

Scaffolding as blending of metacognitive and instructional prompts

METACOGNITIVE PROMPTS
Process

- Content-independent Prompts
- Explicit scaffolding - additional to the task design

INSTRUCTIONAL PROMPTS
Content

- Content-dependent Prompts
- Implicit scaffolding – embedded in the task design

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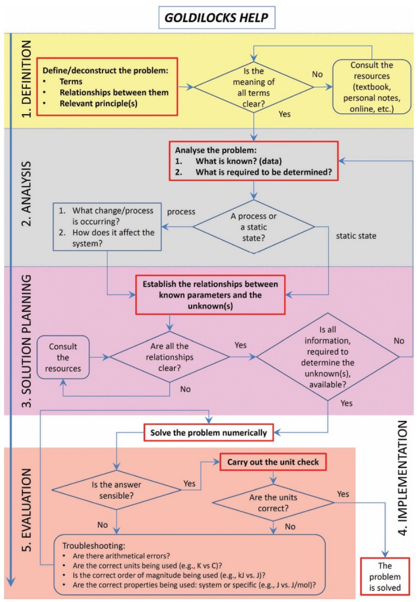
Metacognitive prompts - Problem-solving scaffold

Yuriev, E., Naidu, S., Schembri, L. S., & Short, J. L. (2017). Scaffolding the development of problem-solving skills in chemistry: guiding novice students out of dead ends and false starts. *Chem. Educ. Res. Pract., 18*(3), 486-504.; Yuriev, E. (2019). developing problem-solving skills in physical chemistry. In Overton Festschrift.



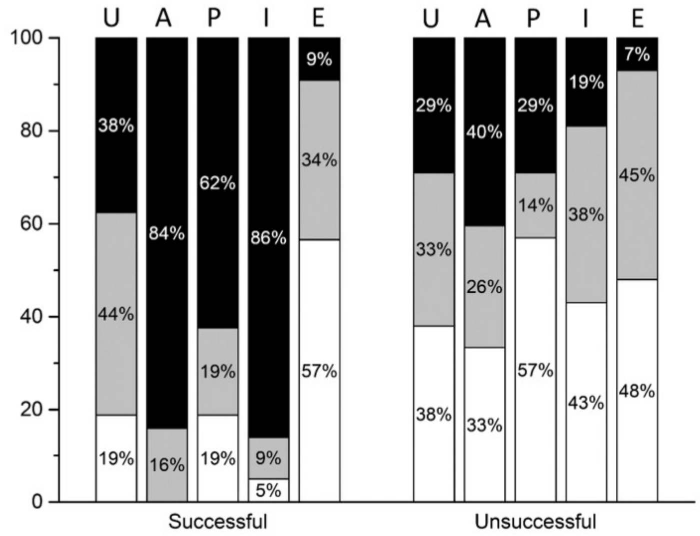
Understand

Analyse

Plan

Implement

Evaluate



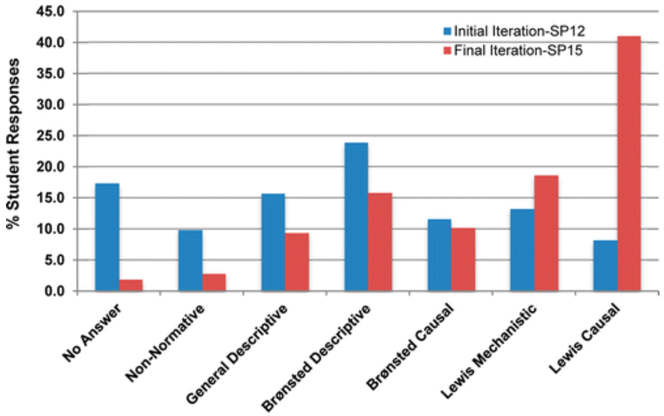
Students applying steps of problem-solving

Instructional prompts

Cooper, M. M.; Kouyoumdjian, H.; Underwood, S. M., Investigating Students' Reasoning about Acid–Base Reactions. *J. Chem. Educ.* **2016**, *93* (10), 1703–1712.

For this reaction:

a. How would you classify the above reaction? Please explain your reasoning.
b. Please explain your reasoning for what you think is happening at the molecular level for this reaction.



For this reaction:

a. How would you classify this reaction? Please explain why you chose that classification.
b. Describe in full detail **what** you think is happening on the molecular level for this reaction. Specifically, discuss the role of each reactant.
c. Using a molecular level explanation, please explain **why** this reaction occurs. Specifically, why the reactants form the products shown.
d. Please draw arrows to indicate how this reaction occurs.

Sequencing is better than just asking to explain reasoning

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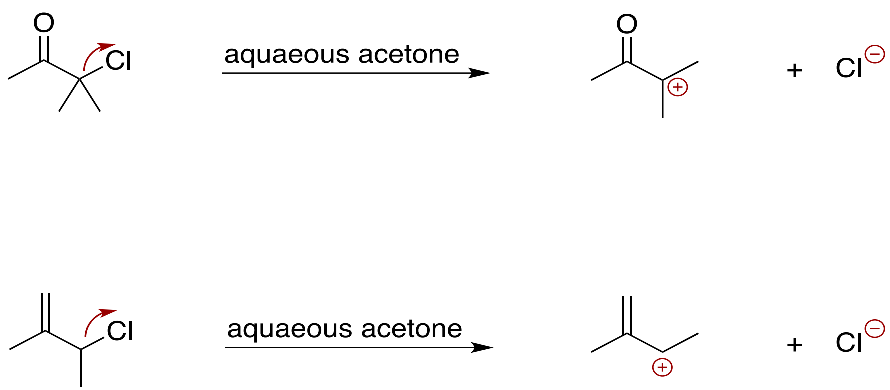
Blending Both - Instructional and metacognitive scaffolding

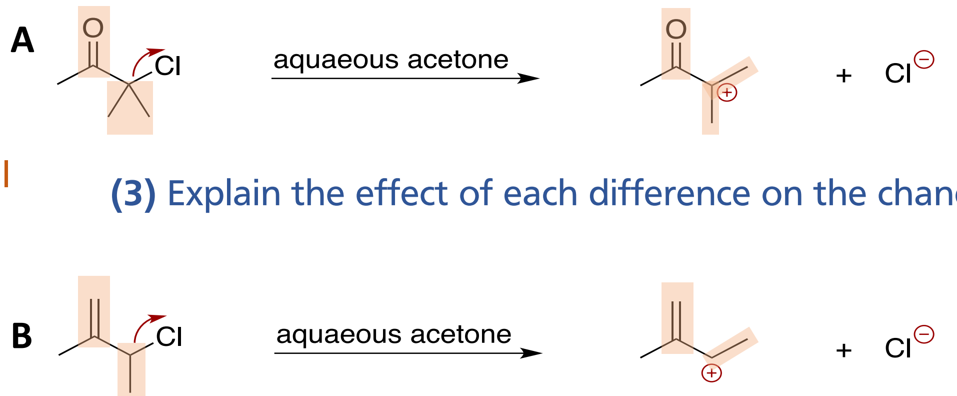
Graulich, N., & Caspari, I. (2020). Designing a scaffold for mechanistic reasoning in organic chemistry. Chemistry Teacher International, 20200001.;
Caspari, I., & Graulich, N. (2019). Scaffolding the Structure of Organic Chemistry Students' multivariate Mechanistic Reasoning. Int. J. Phys. Chem. Educ., 11(2), 31-43.



Predict for which of the two reactants the represented mechanistic step has a lower activation energy.

Blending Both - Instructional and metacognitive scaffolding

Graulich, N., & Caspari, I. (2020). Designing a scaffold for mechanistic reasoning in organic chemistry. Chemistry Teacher International, 20200001.;
Caspari, I., & Graulich, N. (2019). Scaffolding the Structure of Organic Chemistry Students' multivariate Mechanistic Reasoning. Int. J. Phys. Chem. Educ., 11(2), 31-43.



(2) Identify structural differences

(3) Explain the effect of each difference on the change

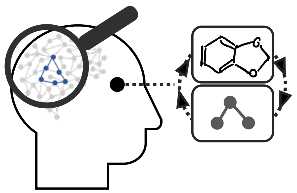
(4) Weigh effects

(1) Identify changes

Predict for which of the two reactants the represented mechanistic step has a lower activation energy.

Cognitive Perspective on Learning

What can we do to fit environment (instruction) and the mind (learner) together?



1 Task Design

- Reasoning is economic (choosing the most accessible information).
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2 Visual Guidance

- Digital instructional tools, such as cueing guide students' attentional focus
- Low prior knowledge students profit from signaling techniques

3 Conceptual Guidance

- Structuring problem-solving processes
- Task-independent scaffolds allow to foster strategic problem-solving skills over various contexts.

X @graulichCER

chemiedidaktik_giessen

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Cooperation partner: Sascha Bernholt & Marc Rodemer (Leibniz Institute for Science and Mathematics Education)

videos

Using Eye Movement Modelling Examples as an Instructional Tool in Organic Chemistry

DFG Deutsche Forschungsgemeinschaft

Must Reads:

Multimedia learning: Schnotz W. (2005) An Integrated Model of Text and Picture Comprehension, in *The Cambridge Handbook of Multimedia Learning*, New York, NY, US: Cambridge University Press, pp. 49-69.

Direct instruction (Scaffolding): Kirschner P. A., Sweller J. & Clark R. E. (2006) Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching, *Educ. Psychol.*, **41**, 75-86.; Graulich N. & Caspari I. (2021) Designing a scaffold for mechanistic reasoning in organic chemistry, *Chem. Teach. Int.*, **3**, 19-30. Doi: 10.1515/cti-2020-0001.

Heuristics : Talanquer V. (2014) Chemistry Education: Ten Heuristics To Tame, J. Chem. Educ., 91, 1091-1097.; Krist C., Schwarz C. V. & Reiser B. J. (2019) Identifying Essential Epistemic Heuristics for Guiding Mechanistic Reasoning in Science Learning, *J. Learn. Sci.*, **28**, 160-205.