Graulich Group
Chemistry Education Research

Justus-Liebig-Universität Giessen

SELAMAT SIANG

Axel Langner, PhD Student

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Chemistry Education Research

JUSTUS-LIEBIG-UNIVERSITAT GIESSEN

Eye-Tracking as a Feedback Tool in Education

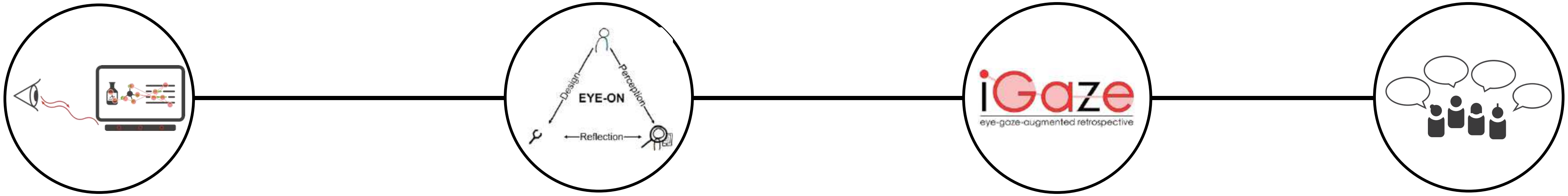
Axel Langner

Nicole Graulich

Graulich Group – Chemistry Education Research

Justus-Liebig-Universität Giessen

AGENDA



Eye-tracking

… as a feedback tool in **teacher education**

… as a feedback tool in **chemistry education**

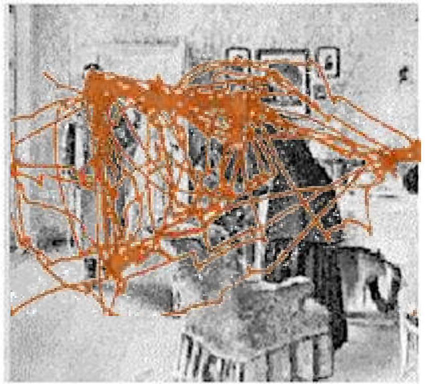
Discussion

Eye movements

Yarbus 1967

EYE MOVEMENTS

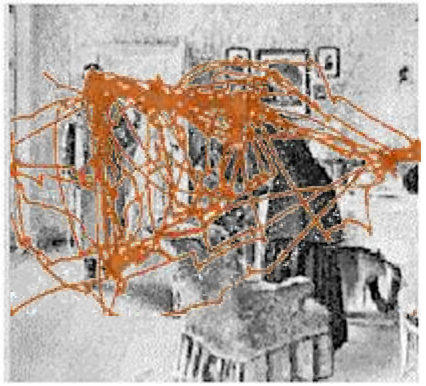
Examine the picture



Yarbus 1967

EYE MOVEMENTS

Examine the picture

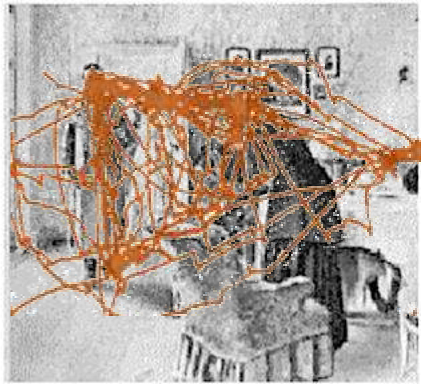


Remember clothing

Yarbus 1967

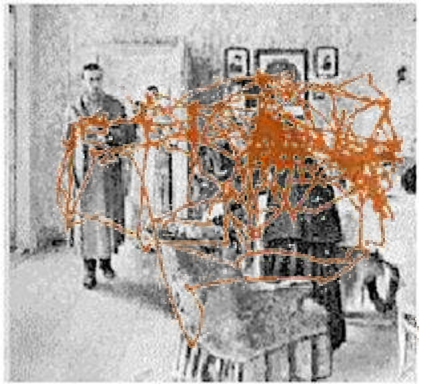
Eye movements

Examine the picture



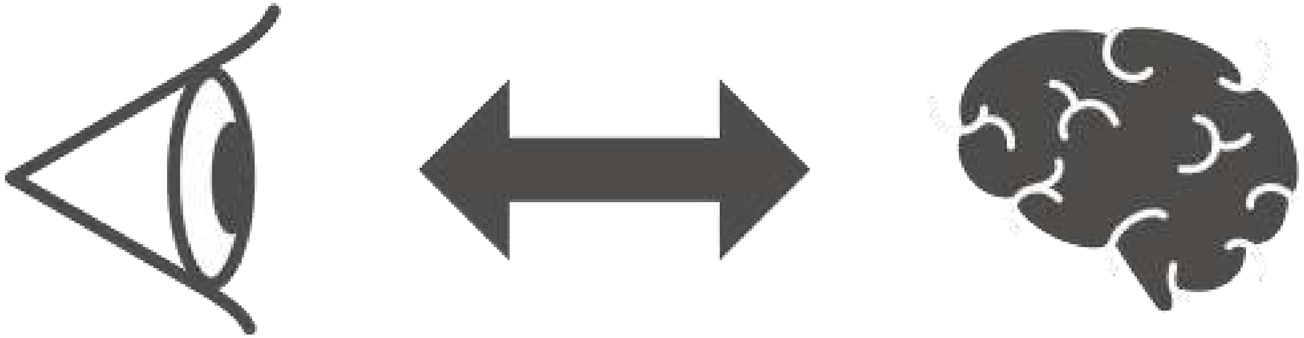
Remember clothing

Estimate economic level



Yarbus 1967

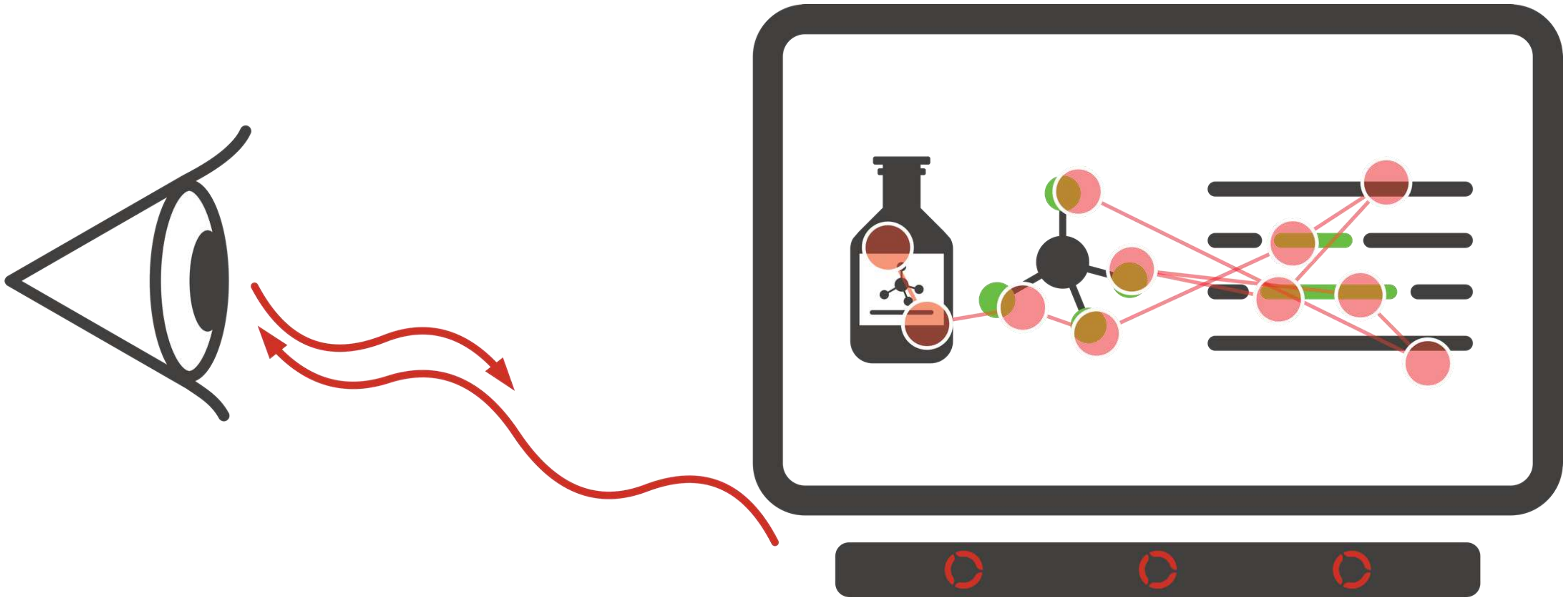
Gaze & Cognition



Eye movements and cognitive processes are interconnected.

Land & Tatler 2009 & Yarbus 1967

EYE-TRACKING



Eye-tracker

Holmqvist *et al.* 2011, Duchowski 2017

DATA COLLECTION

Screen-based

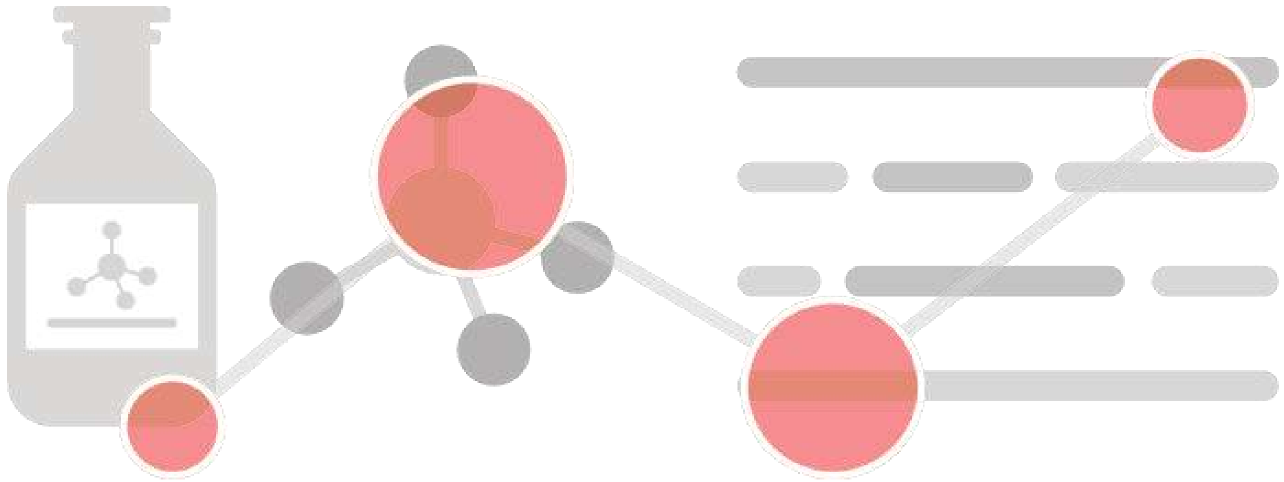
DATA COLLECTION

Screen-based

Mobile

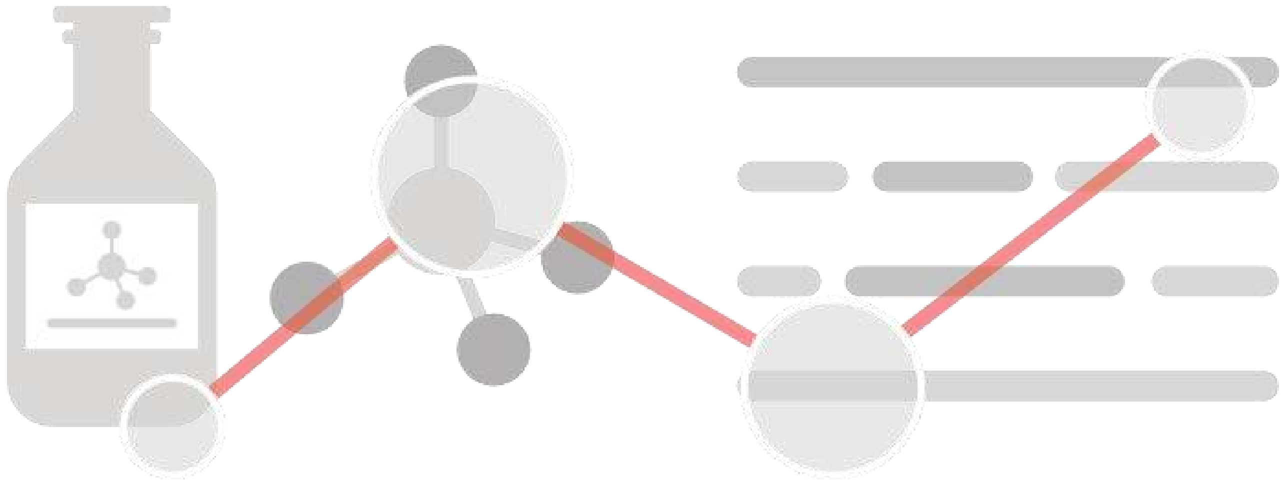
EYE-TRACKING

Fixations



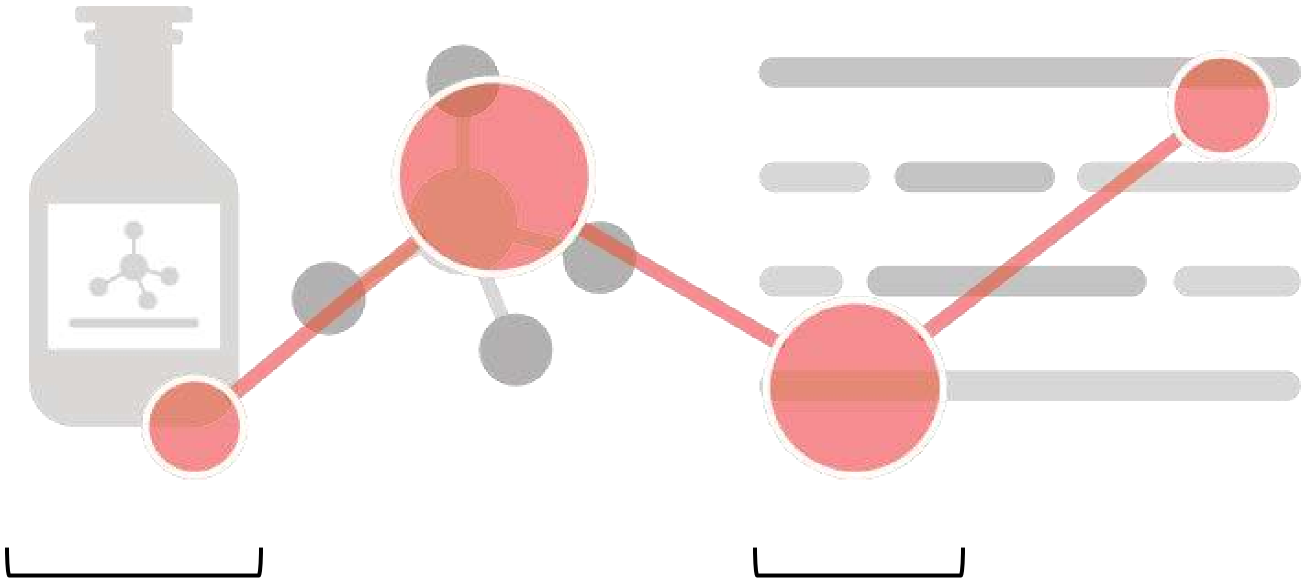
Eye-Tracking

Saccades



Holmqvist *et al.* 2011, Duchowski 2017

EYE-TRACKING



What?

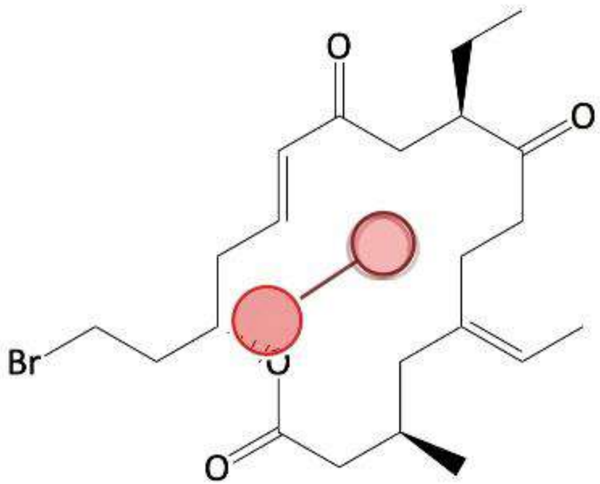
How long?

In which order?

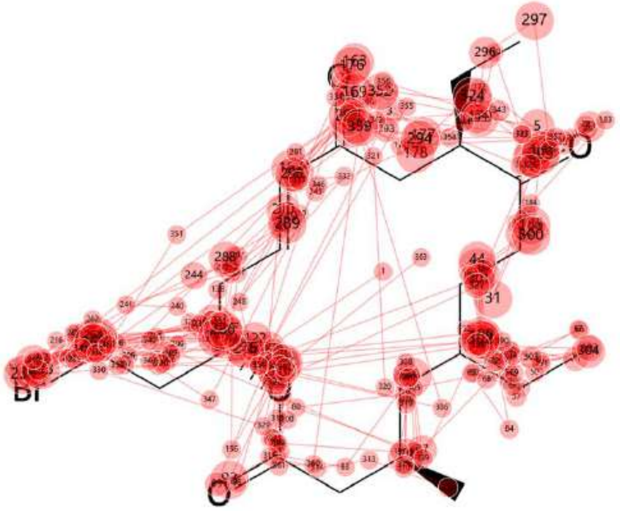
Holmqvist *et al.* 2011, Duchowski 2017

OUTPUT

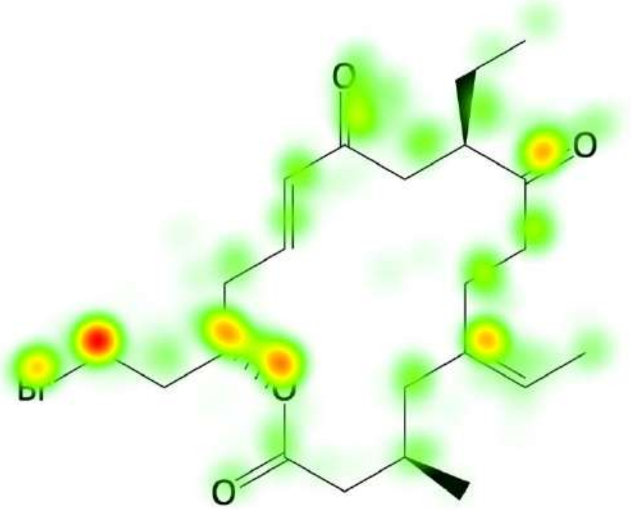
Task prompt: Identify electrophilic centers.



Replay

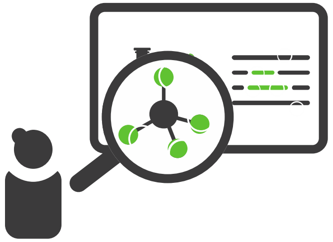


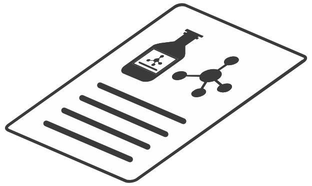
Gaze plot



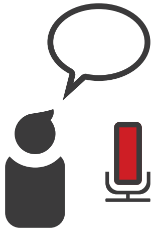
Heat map

METHODOLOGICAL TRIANGULATION

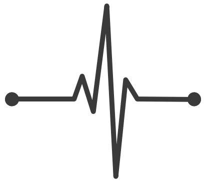




Questionnaires (e.g., surveys, reports, prior knowledge test, performance)



Verbal reports (e.g., think aloud)



Biometrics (e.g., electroencephalography, galvanic skin response)

Holmqvist *et al.* 2011, Duchowski 2017

Marketing

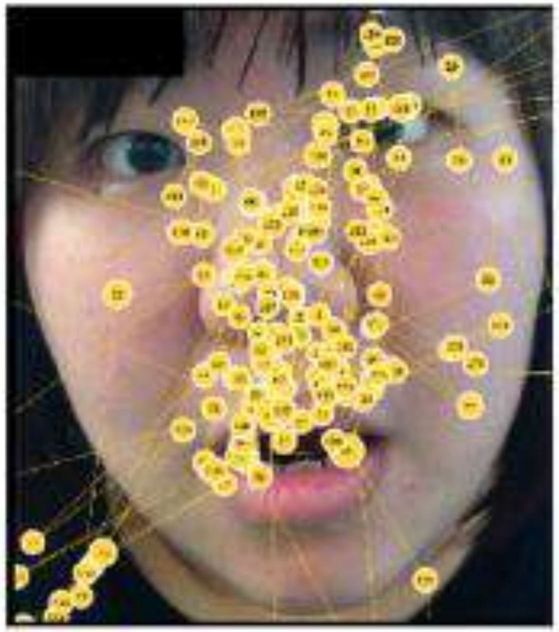
Influence of the car brand

Perodua Nautica   Toyota Rush

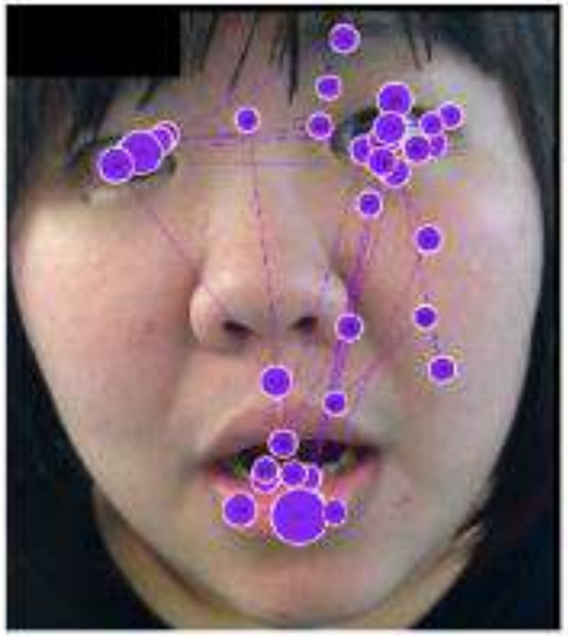
Zamani *et al.* 2016

PSYCHOLOGY

Facial emotion recognition



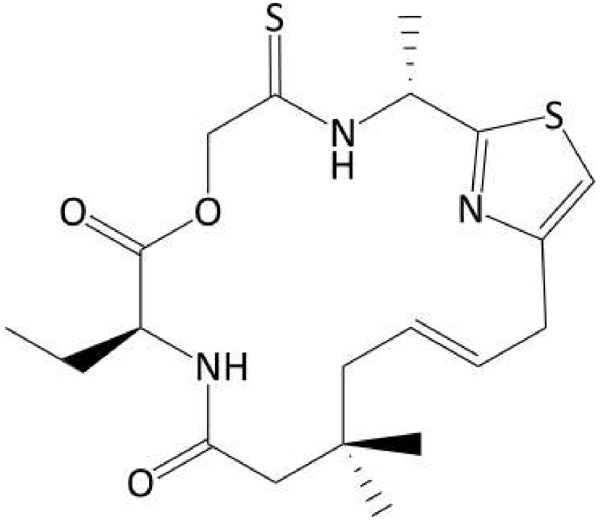
…with
autism spectrum disorder



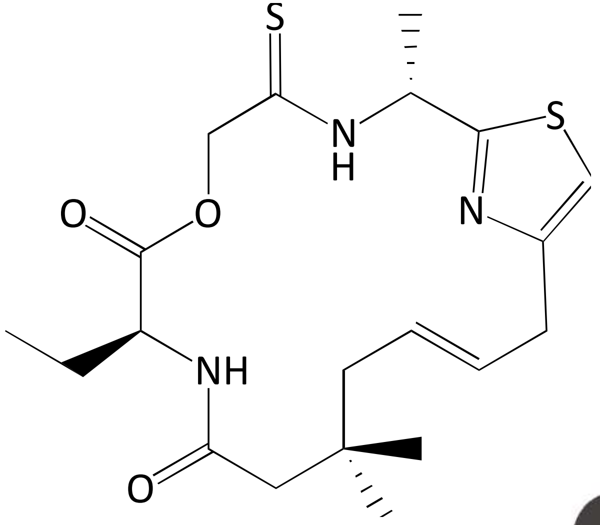
…without
autism spectrum disorder

Tsang 2018

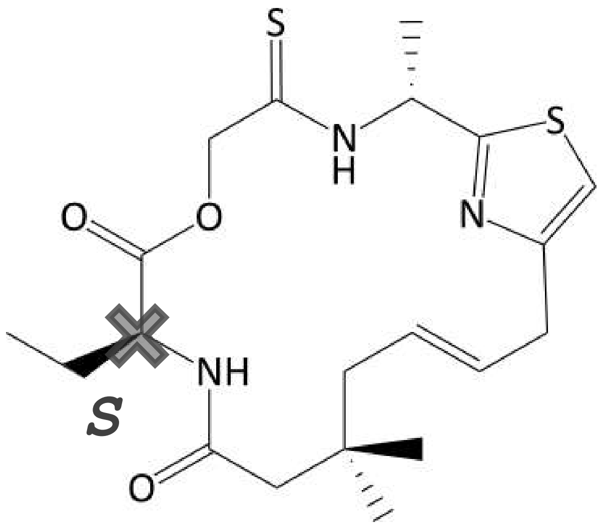
EDUCATION

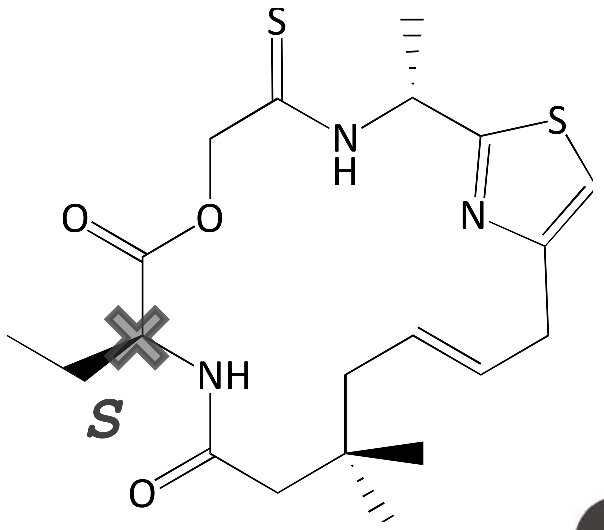


Determine the configuration of the asymmetric carbon atoms (R/S configuration).

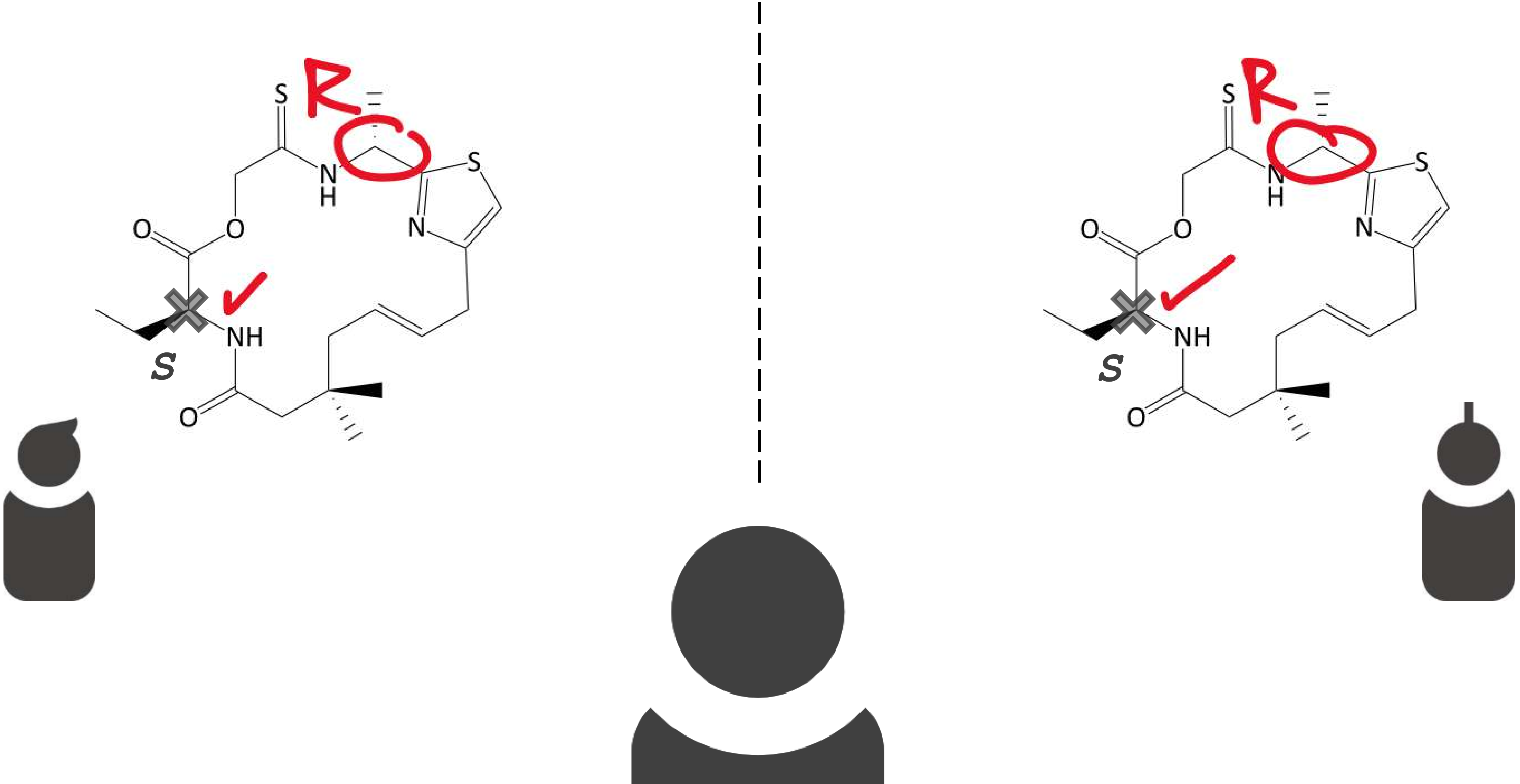


EDUCATION

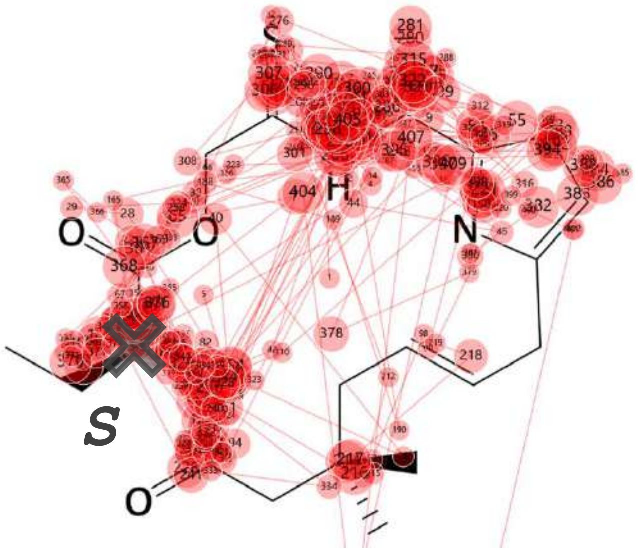


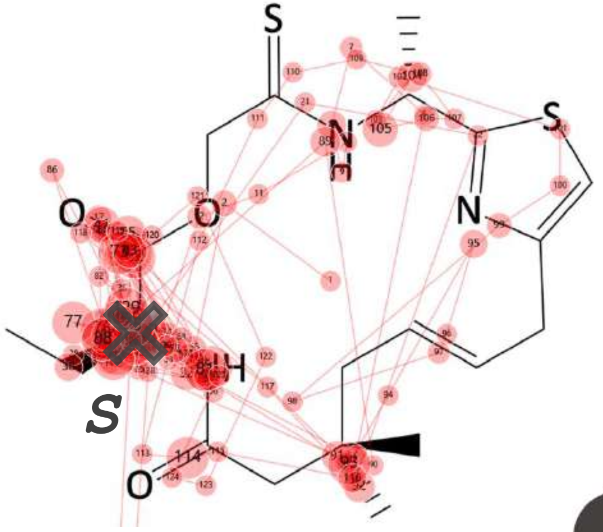


EDUCATION



EDUCATION





ET IN CHEMISTRY EDUCATION RESEARCH

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Chemistry Education Research

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Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability

ET IN CHEMISTRY EDUCATION RESEARCH

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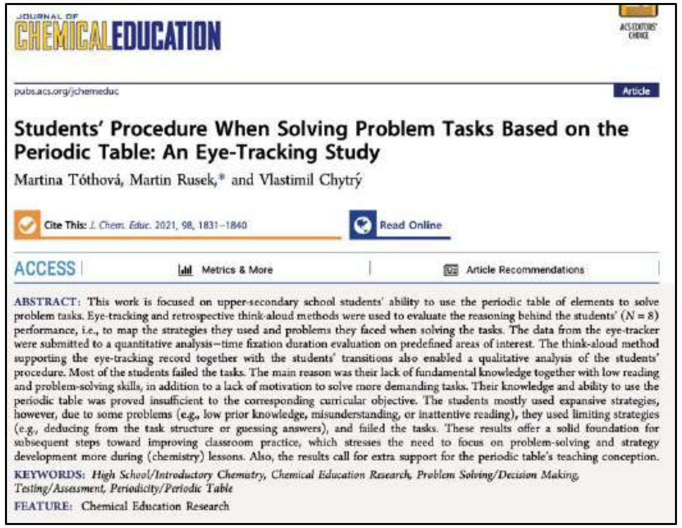


JOURNAL OF CHEMICAL EDUCATION

ACS EDITORS' CHOICE

pubs.acs.org/jchemeduc Article

Students' Procedure When Solving Problem Tasks Based on the Periodic Table: An Eye-Tracking Study

Martina Tóthová, Martin Rusek,* and Vlastimil Chytrý

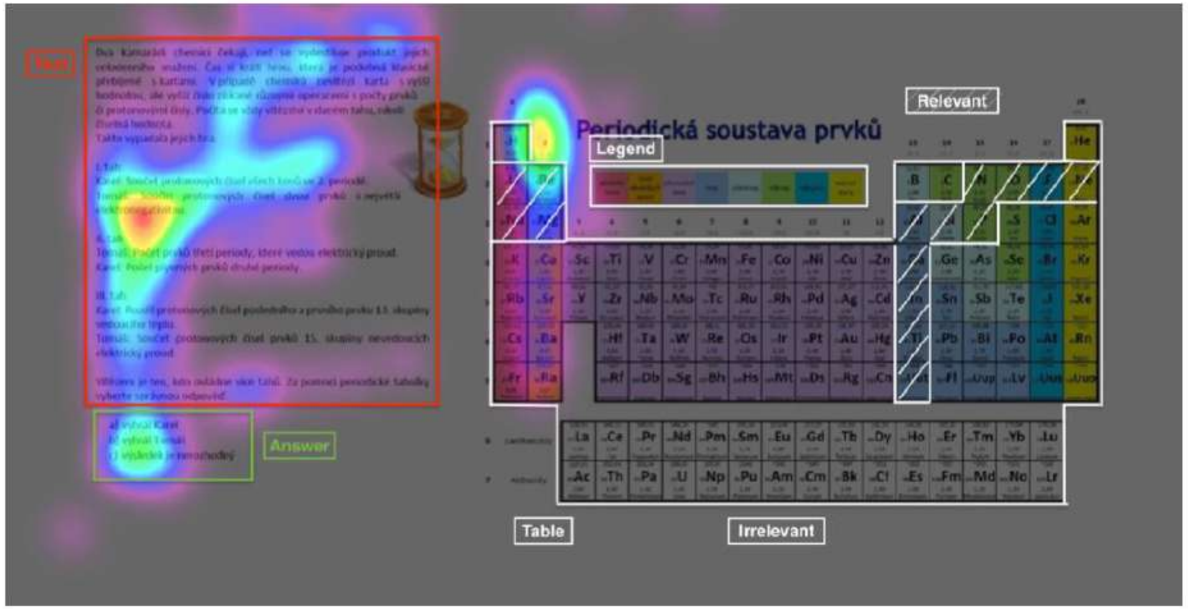
Cite This: *J. Chem. Educ.* 2021, 98, 1831−1840 Read Online

ACCESS | Metrics & More | Article Recommendations

ABSTRACT: This work is focused on upper-secondary school students' ability to use the periodic table of elements to solve problem tasks. Eye-tracking and retrospective think-aloud methods were used to evaluate the reasoning behind the students' ($N = 8$) performance, i.e., to map the strategies they used and problems they faced when solving the tasks. The data from the eye-tracker were submitted to a quantitative analysis−time fixation duration evaluation on predefined areas of interest. The think-aloud method supporting the eye-tracking record together with the students' transitions also enabled a qualitative analysis of the students' procedure. Most of the students failed the tasks. The main reason was their lack of fundamental knowledge together with low reading and problem-solving skills, in addition to a lack of motivation to solve more demanding tasks. Their knowledge and ability to use the periodic table was proved insufficient to the corresponding curricular objective. The students mostly used expansive strategies, however, due to some problems (e.g., low prior knowledge, misunderstanding, or inattentive reading), they used limiting strategies (e.g., deducing from the task structure or guessing answers), and failed the tasks. These results offer a solid foundation for subsequent steps toward improving classroom practice, which stresses the need to focus on problem-solving and strategy development more during (chemistry) lessons. Also, the results call for extra support for the periodic table's teaching conception.

KEYWORDS: *High School/Introductory Chemistry, Chemical Education Research, Problem Solving/Decision Making, Testing/Assessment, Periodicity/Periodic Table*

FEATURE: Chemical Education Research

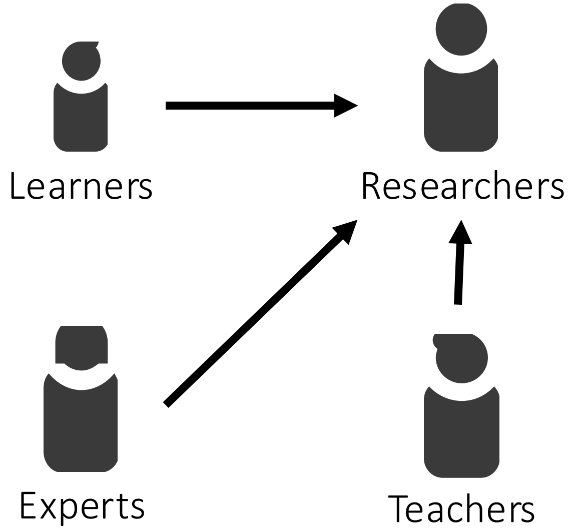


Pupils scantily used the periodic table and often **memorized or guessed**.

ET IN CHEMISTRY EDUCATION RESEARCH

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability

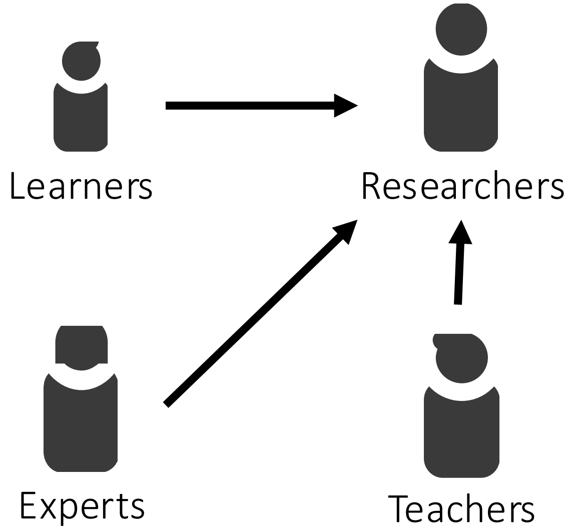


ET IN CHEMISTRY EDUCATION RESEARCH

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability

Learning



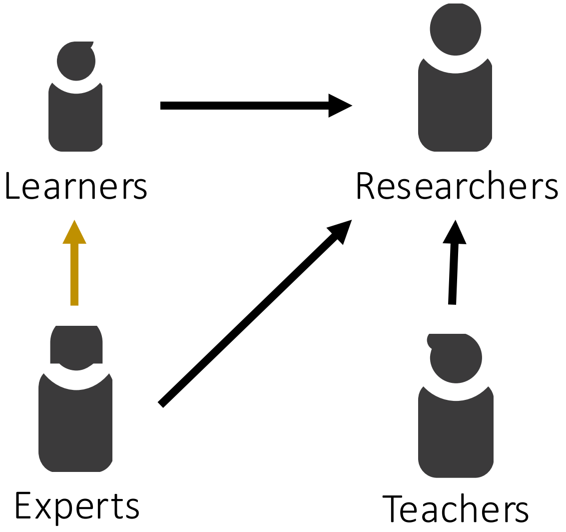
ET IN CHEMISTRY EDUCATION RESEARCH

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability

Learning

Eye movement modeling examples



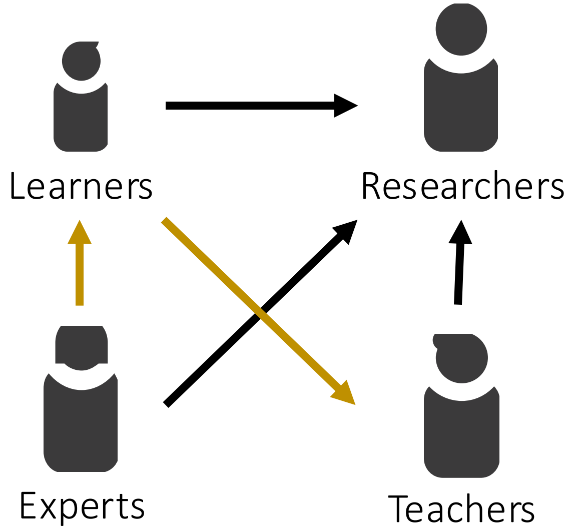
ET IN CHEMISTRY EDUCATION RESEARCH

Diagnosis & Assessment

- Problem-solving strategies
- Expertise comparisons
- Usage of representations
- Evaluation of learning materials
- Cognitive demand
- Predictability

Learning

- Eye movement modeling examples
- Teaching expertise development



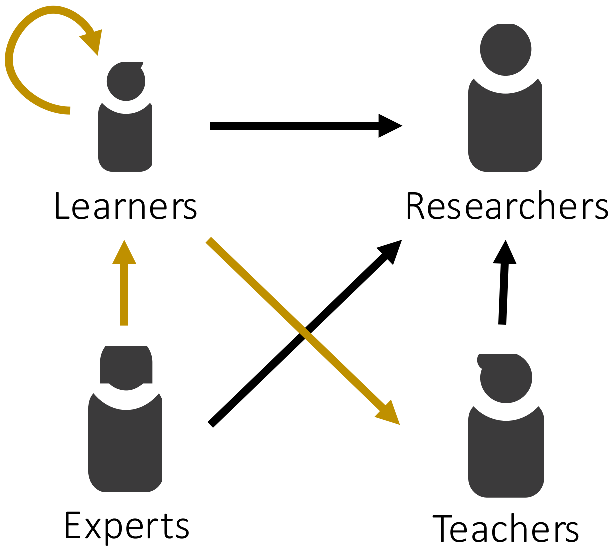
ET IN CHEMISTRY EDUCATION RESEARCH

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability

Learning

Eye movement modeling examples | Teaching expertise development | Scientific expertise development



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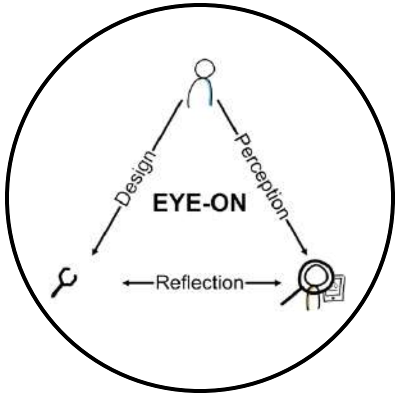
NOVEL WAYS

Diagnosis & Assessment

- Problem-solving strategies
- Expertise comparisons
- Usage of representations
- Evaluation of learning materials
- Cognitive demand
- Predictability

Learning

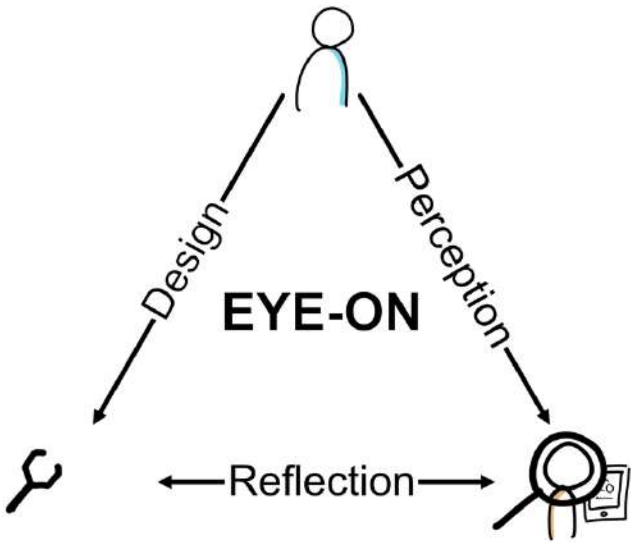
- Eye movement modeling examples
- Teaching expertise development
- Scientific expertise development



iGaze
eye-gaze-augmented retrospective

Designing multimedia learning materials &

investigating the perceptual process of the learner



OUR GOAL

Supporting

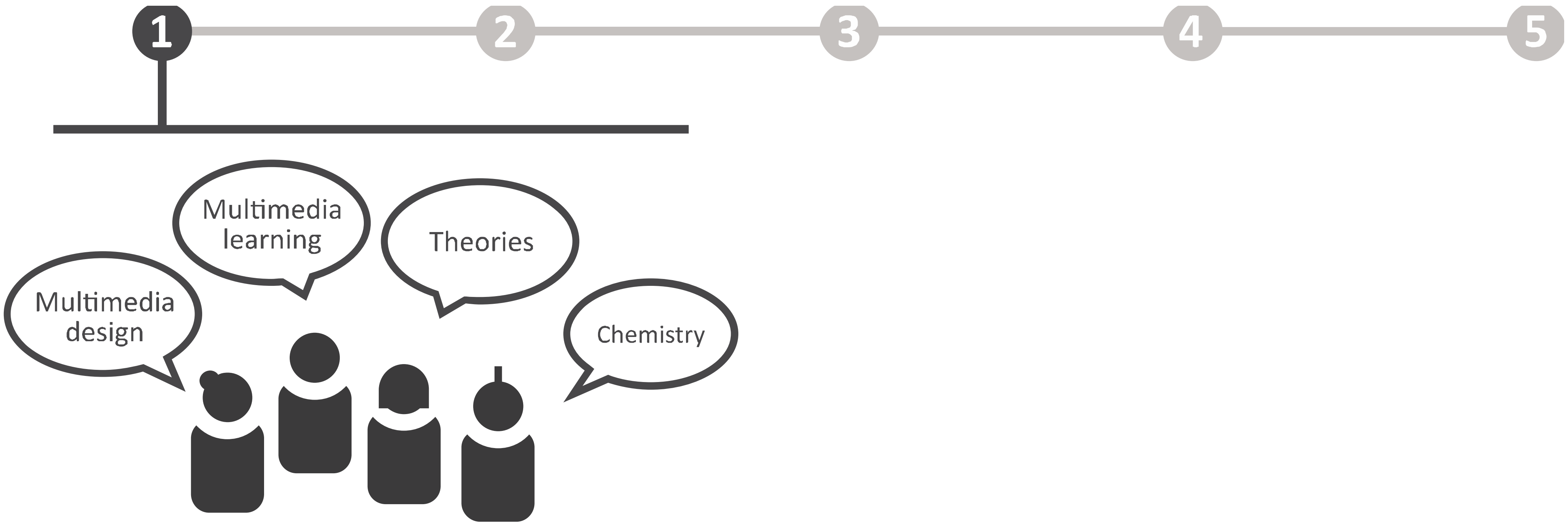
by

learning material design

offering insight into learners’ visual behavior.

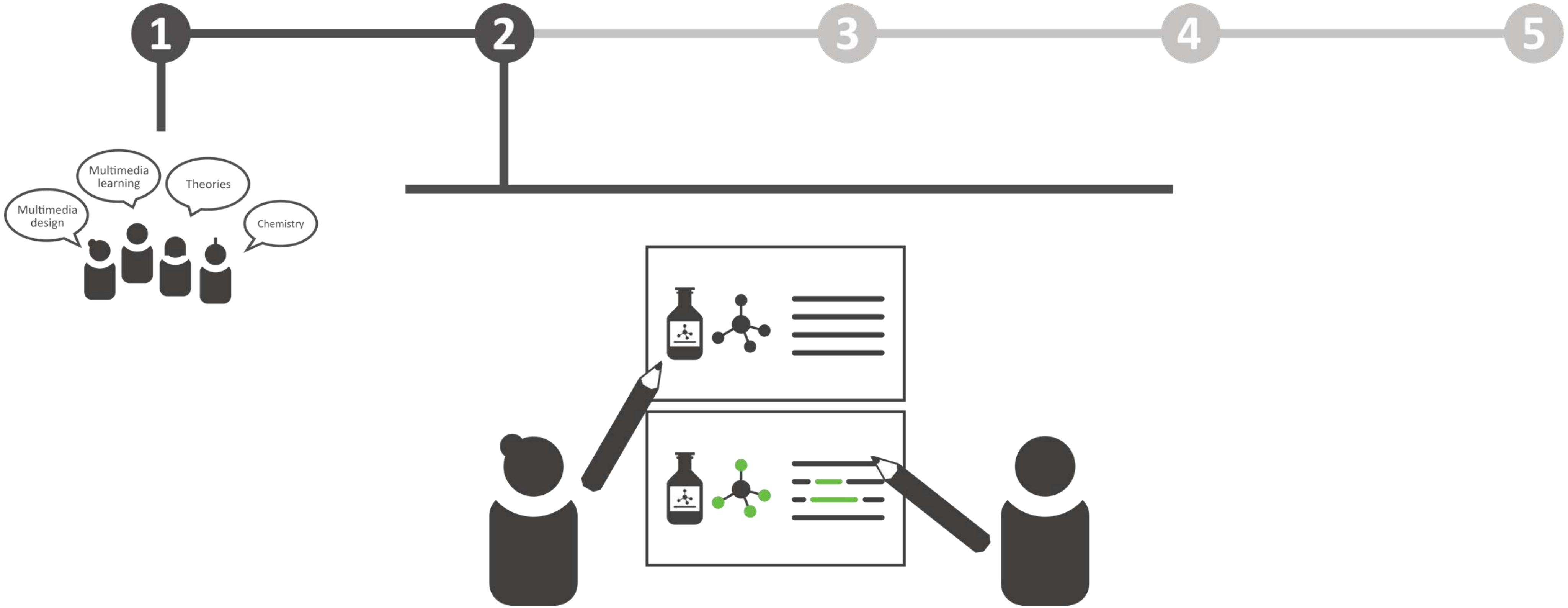
Langner *et al.* 2022

Course design



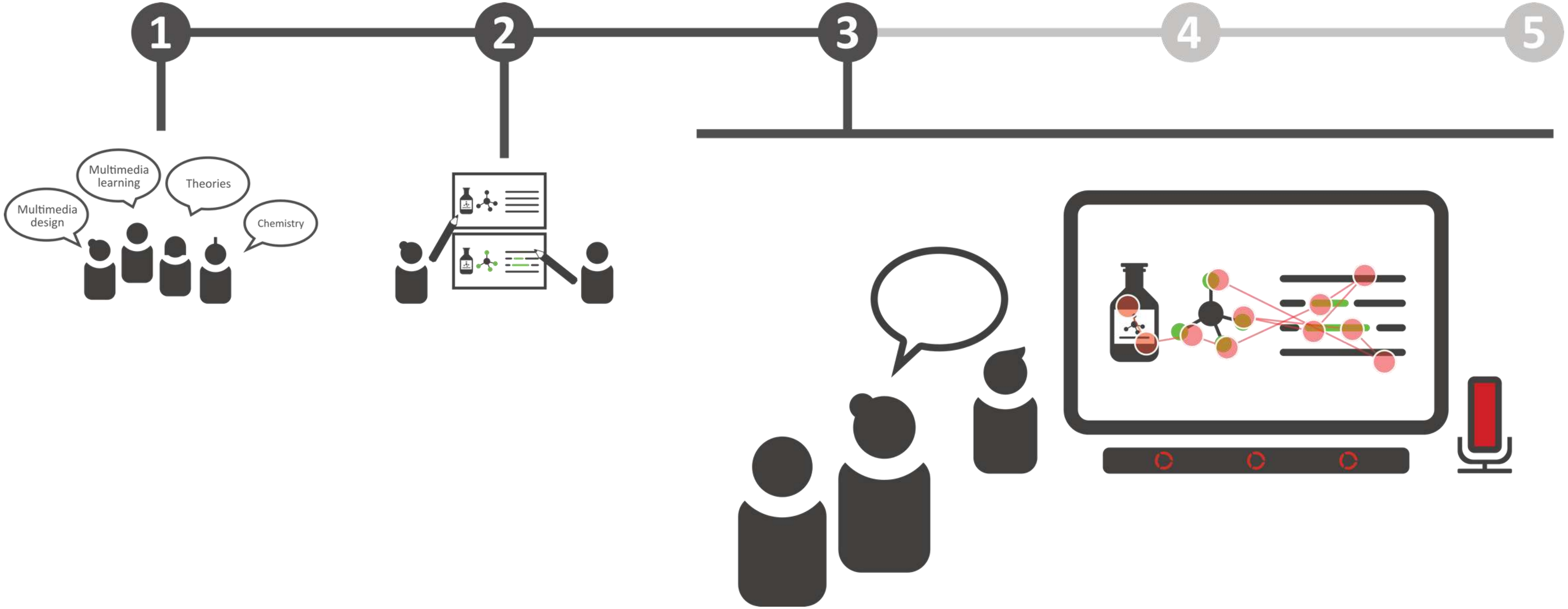
Langner *et al.* 2022

Course design



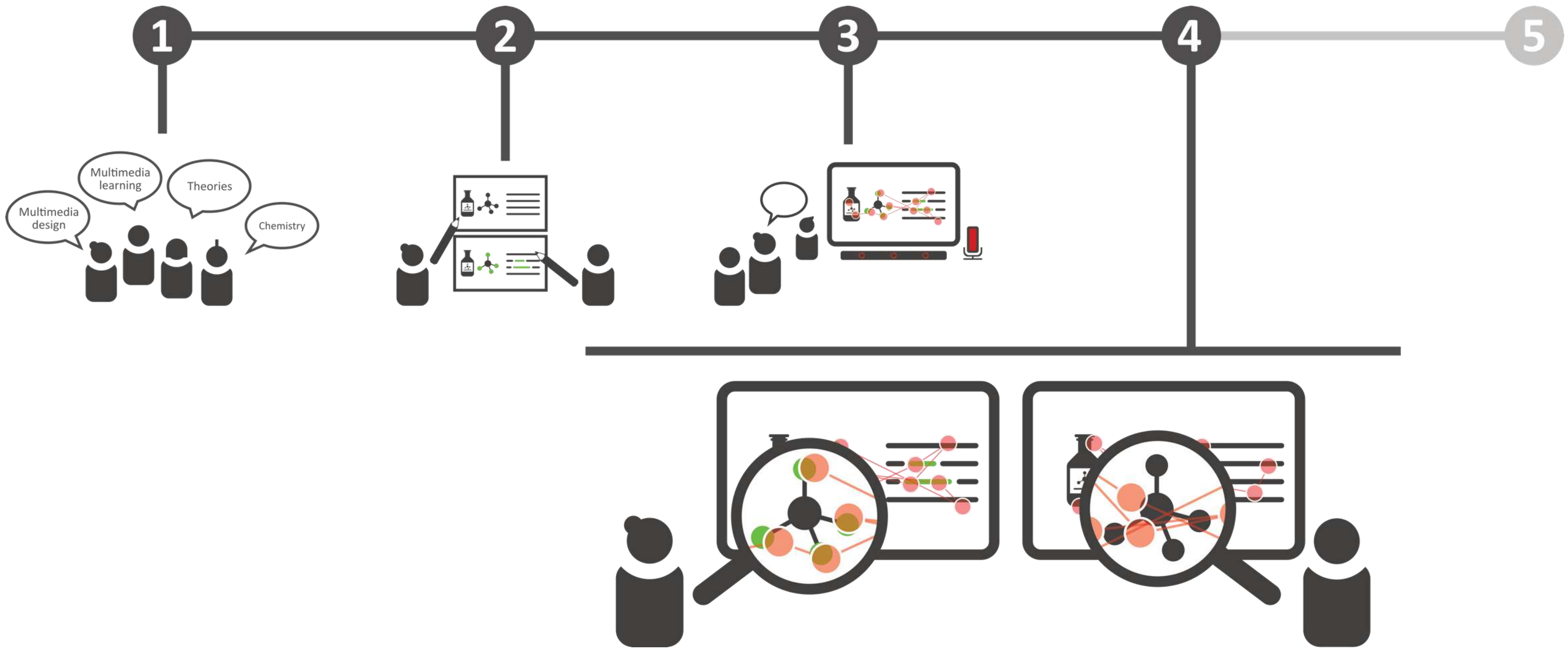
Langner *et al.* 2022

COURSE DESIGN



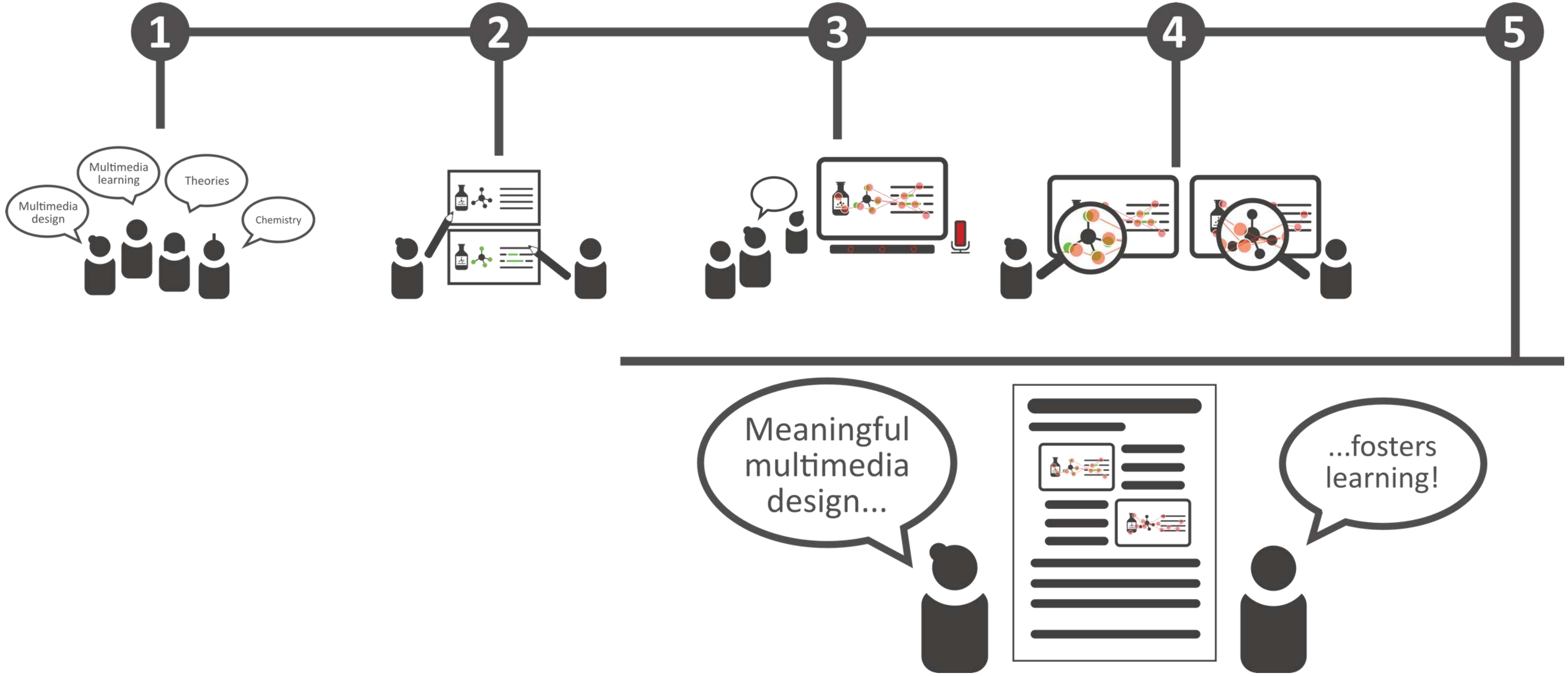
Langner *et al.* 2022

COURSE DESIGN



Langner *et al.* 2022

COURSE DESIGN



Langner *et al.* 2022

COURSE DESIGN

GRAULICH GROUP
Chemistry Education Research

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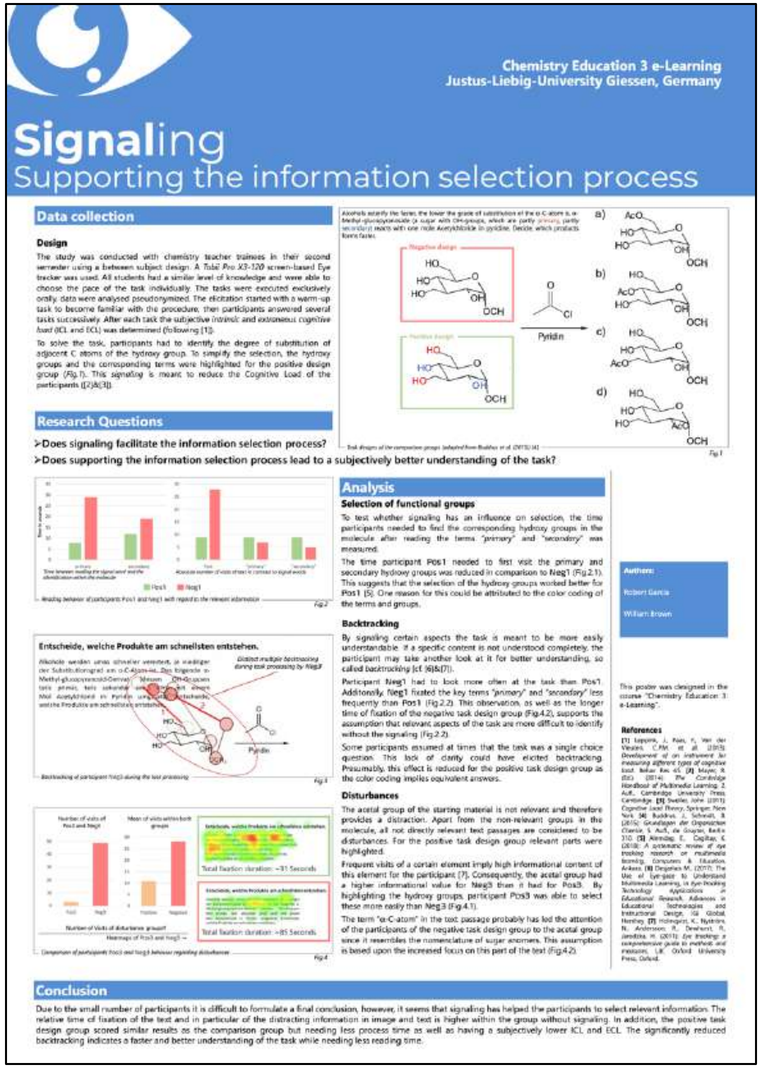
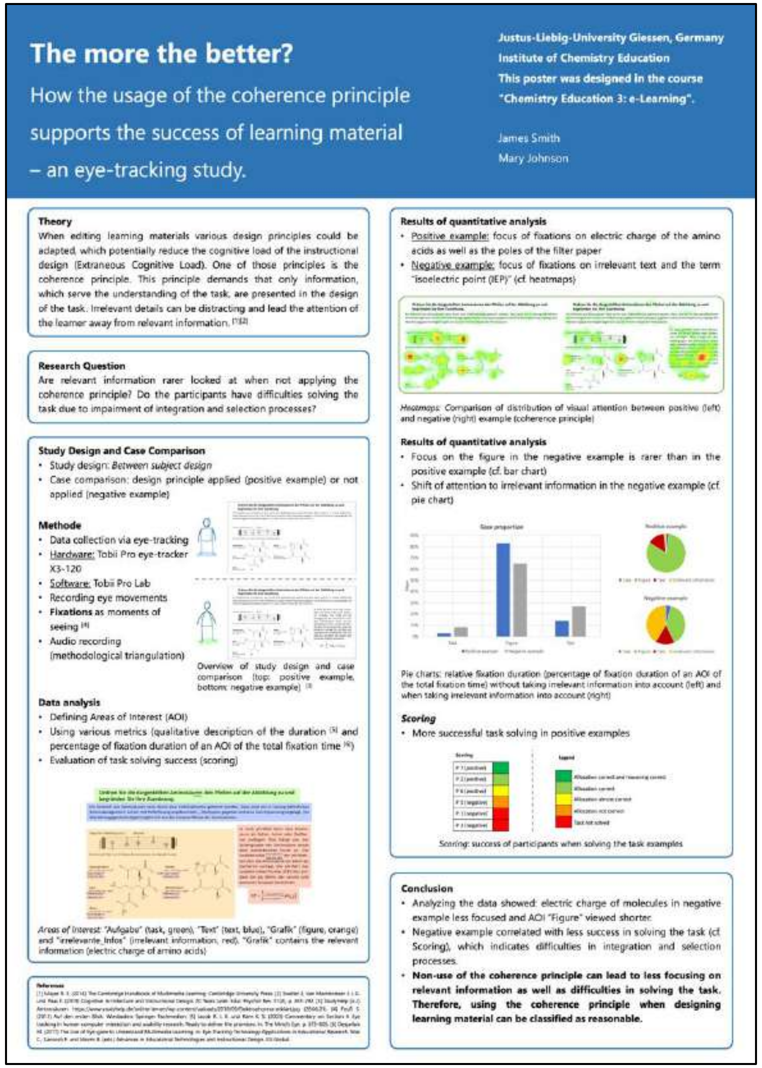
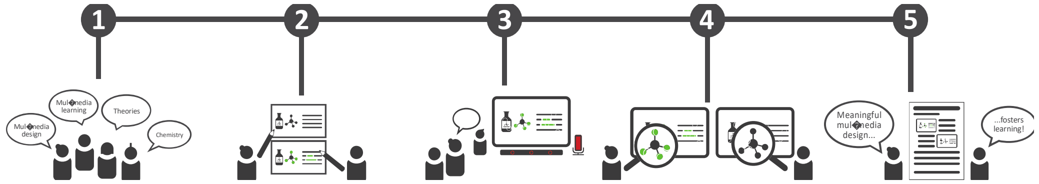


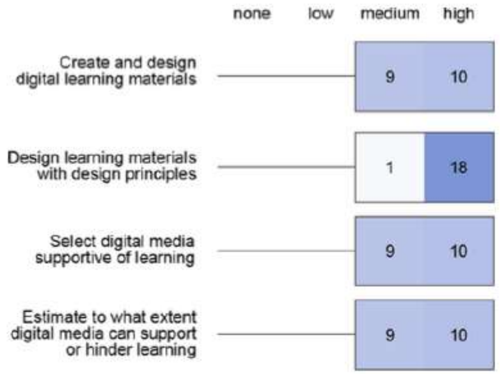


Langner *et al.* 2022

Teaching expertise development



The course **increased** student teachers…



…skills to **create, select, and design** learning material.

constructs	median	z	p^a	r^b
Attitude (pre)	3.00	2.11	0.035	0.48
Attitude (post)	3.28			
Subjective norm expectations (pre)	2.75	2.67	0.008	0.61
Subjective norm expectations (post)	3.00			
Self-efficacy expectations (pre)	2.14	2.44	0.015	0.56
Self-efficacy expectations (post)	2.57			

[a]Significance level of 0.05 and confidence interval of 95%. [b]Calculated as indicated by Rosenthal.[86]

…**attitude and self-efficacy** toward digital media use in teaching.

Langner *et al.* 2022

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

Eye-Tracking Research CER Graulich Group
Graulich Group Chemistry Education Research
Justus-Liebig-Universität Giessen

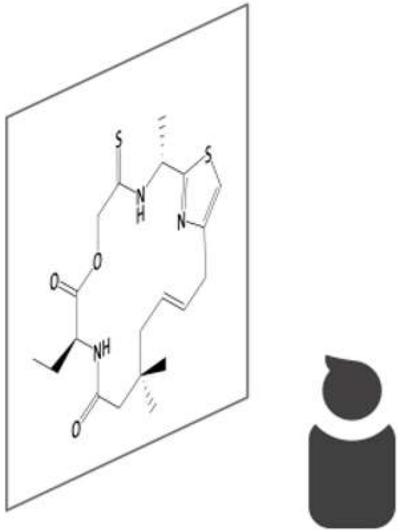
An eye-gaze-augmented retrospective

in Organic Chemistry

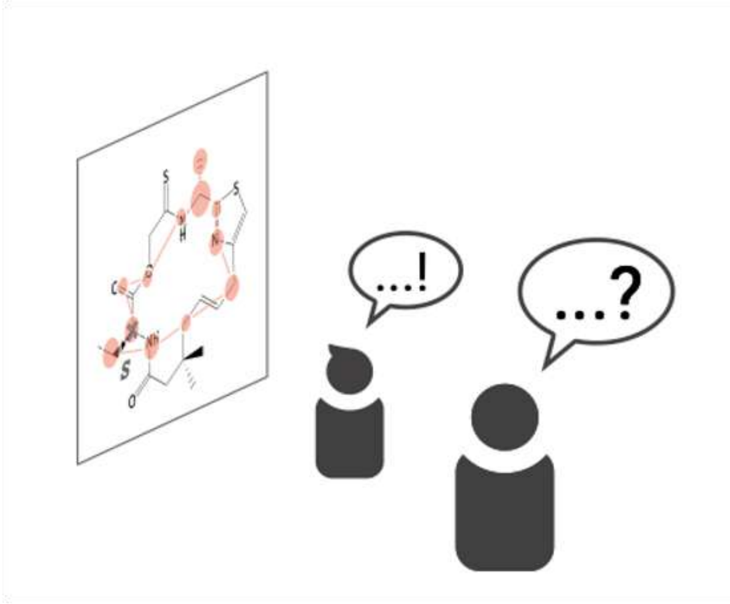
iGaze
eye-gaze-augmented retrospective

OUR GOAL

Supporting



with

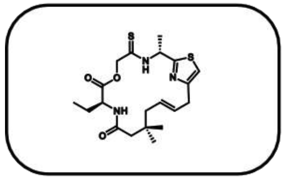


students' problem-solving

an eye-gaze-augmented retrospective.

STUDY DESIGN

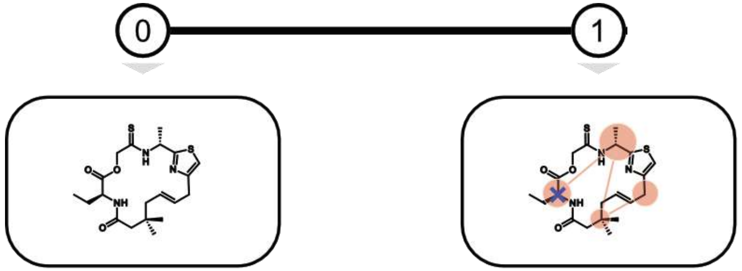
0



Task

Retrospective based on ALACT-model of Korthagen 1985

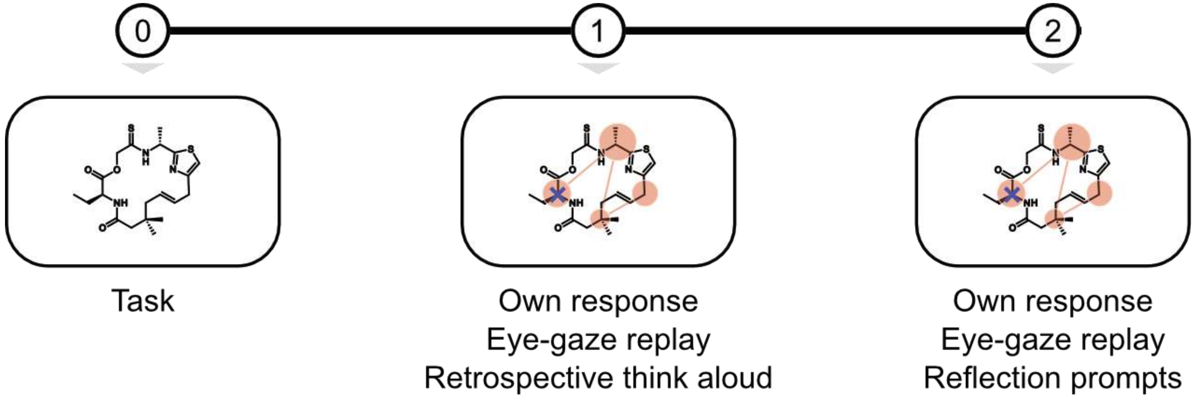
STUDY DESIGN



Task

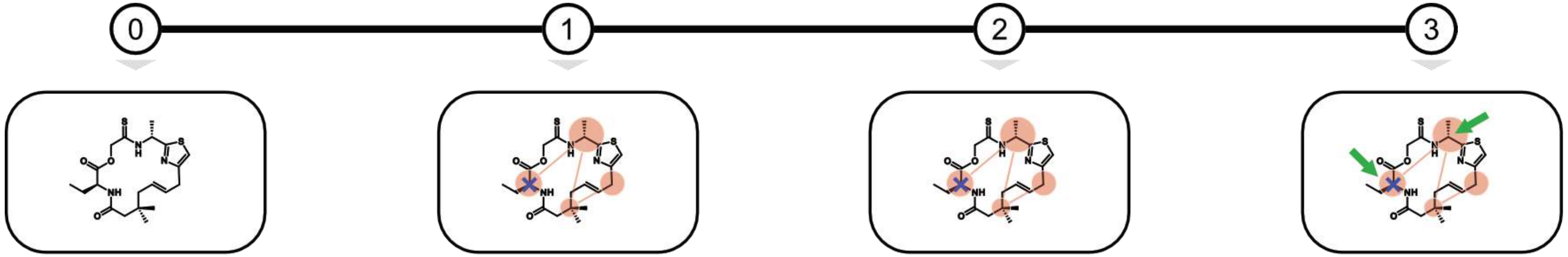
Own response
Eye-gaze replay
Retrospective think aloud

STUDY DESIGN



Retrospective based on ALACT-model of Korthagen 1985

STUDY DESIGN



Task

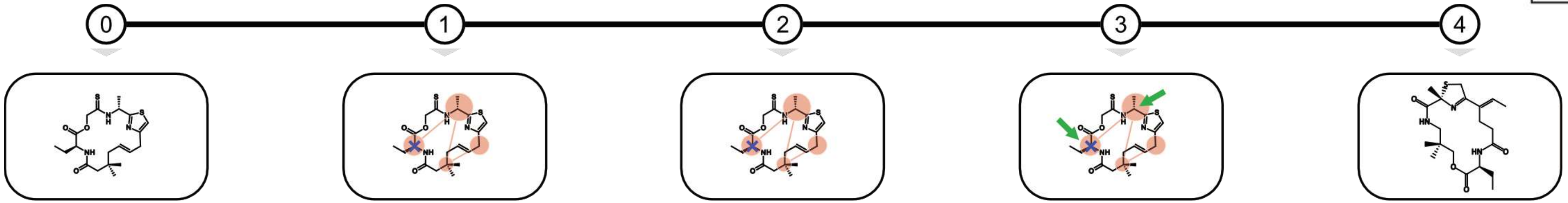
Own response
Eye-gaze replay
Retrospective think aloud

Own response
Eye-gaze replay
Reflection prompts

Own response
Eye-gaze replay
Reflection prompts
Task solution

Retrospective based on ALACT-model of Korthagen 1985

STUDY DESIGN



0 – Task

1 – Own response; Eye-gaze replay; Retrospective think aloud

2 – Own response; Eye-gaze replay; Reflection prompts

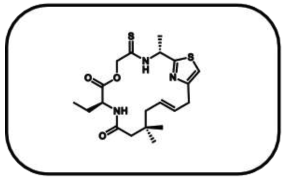
3 – Own response; Eye-gaze replay; Reflection prompts; Task solution

4 – Task

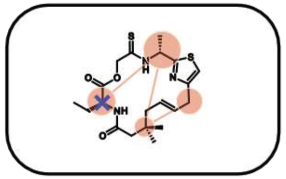
Retrospective based on ALACT-model of Korthagen 1985

Study design

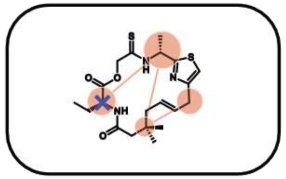
0 — 1 — 2 — 3 — 4



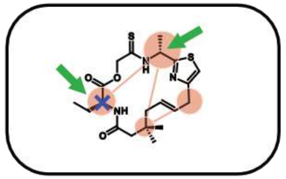
Task



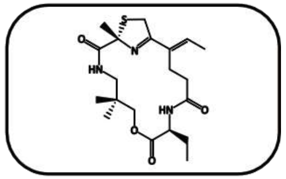
Own response
Eye-gaze replay
Retrospective think aloud



Own response
Eye-gaze replay
Reflection prompts



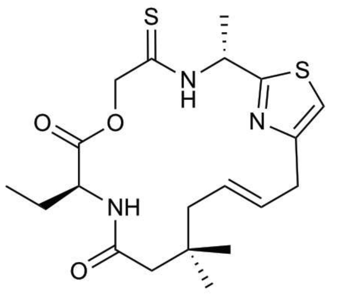
Own response
Eye-gaze replay
Reflection prompts
Task solution



Task

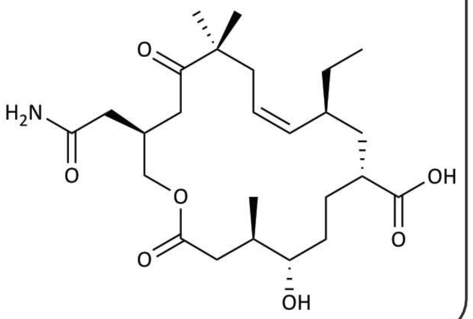
Ⓐ **R/S configuration of asymmetric carbon atoms**

Determine the configuration of the asymmetric carbon atoms (R/S configuration).



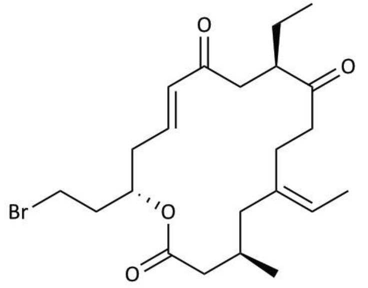
Ⓑ **Brønsted acid-base concept**

Identify the four positions where the molecule is most likely to be deprotonated by a strong base.

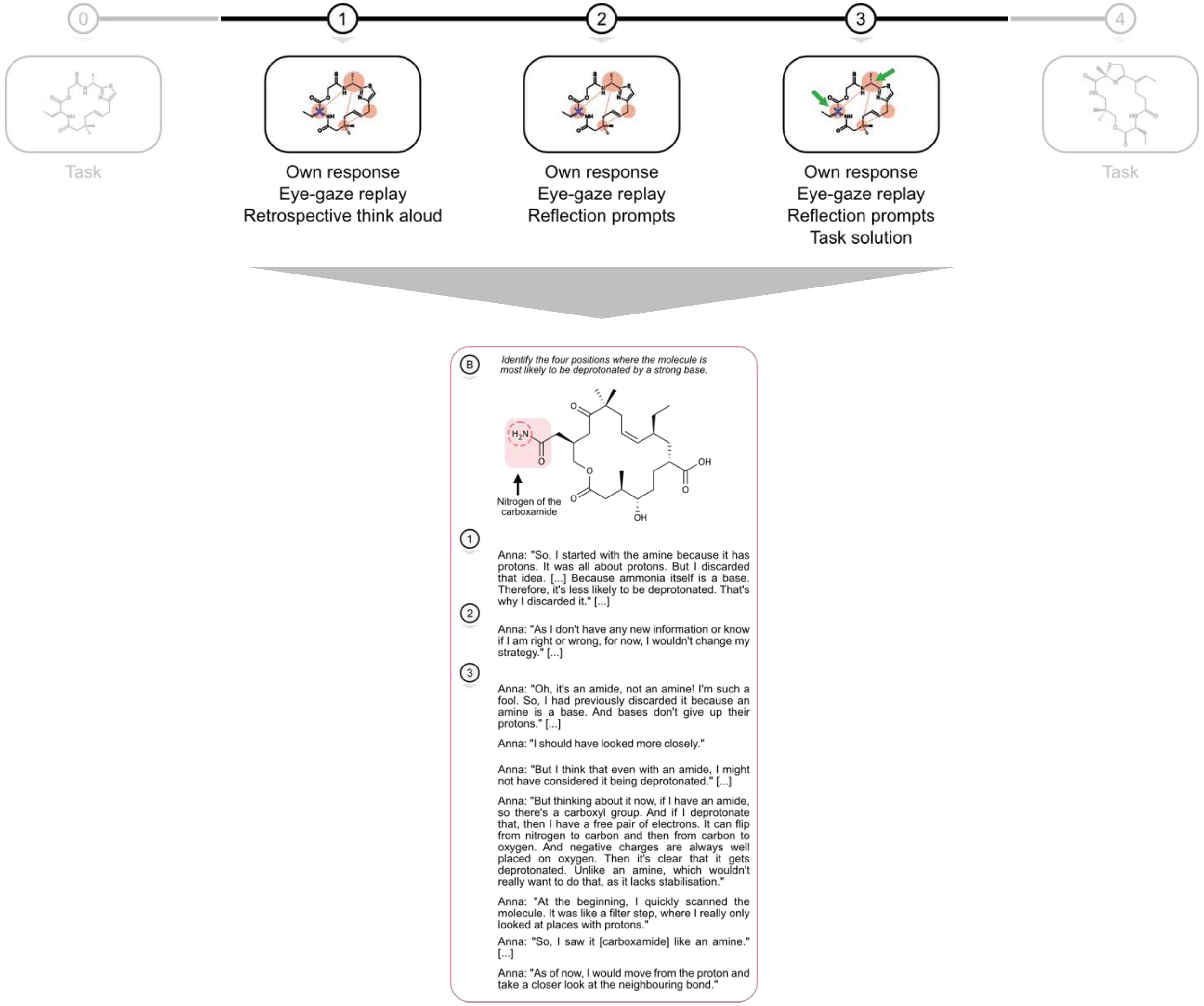


Ⓒ **Electrophilicity and nucleophilicity**

Identify electrophilic centres. These are those that can be attacked by a nucleophile.

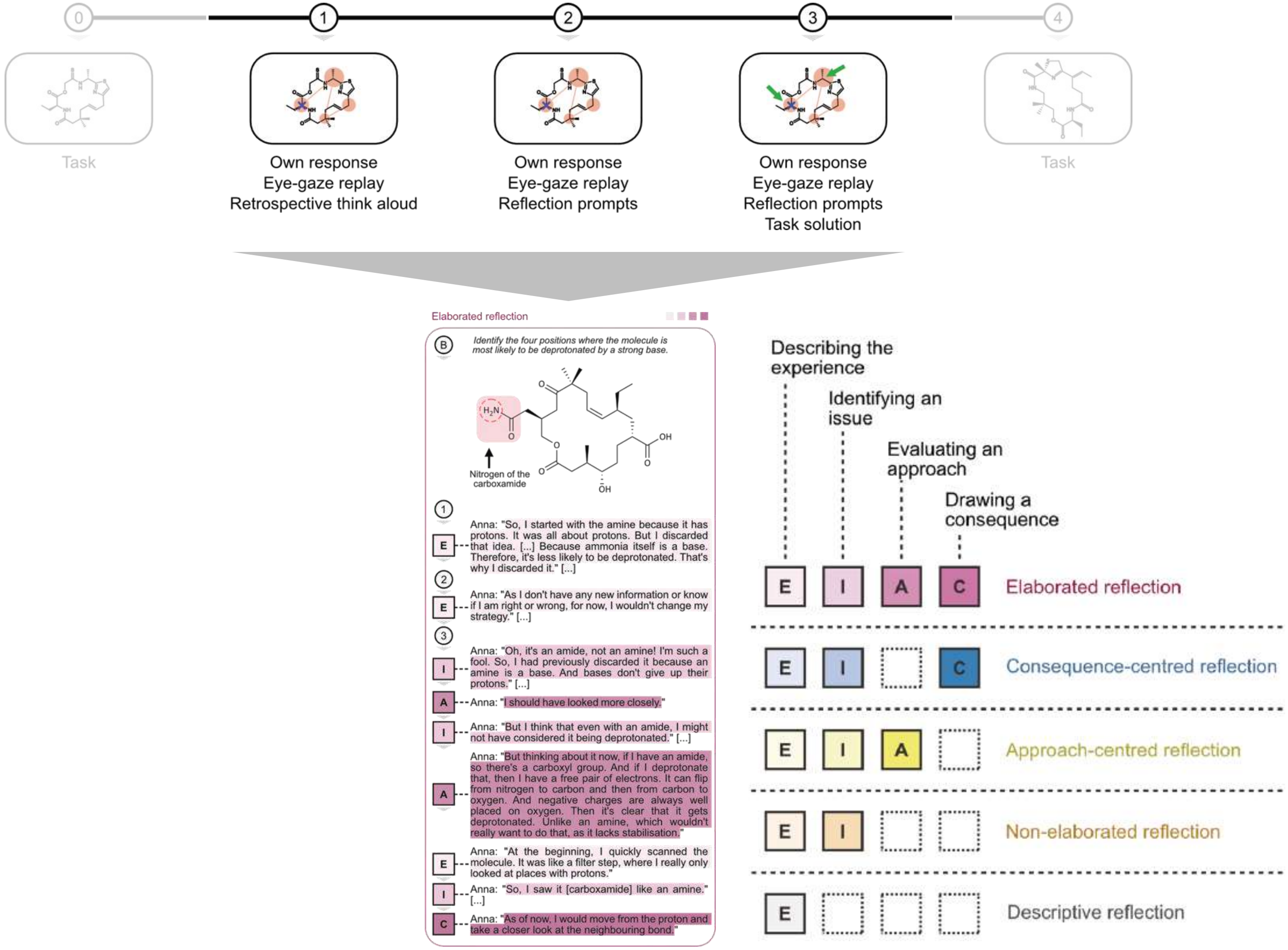


Scientific expertise development



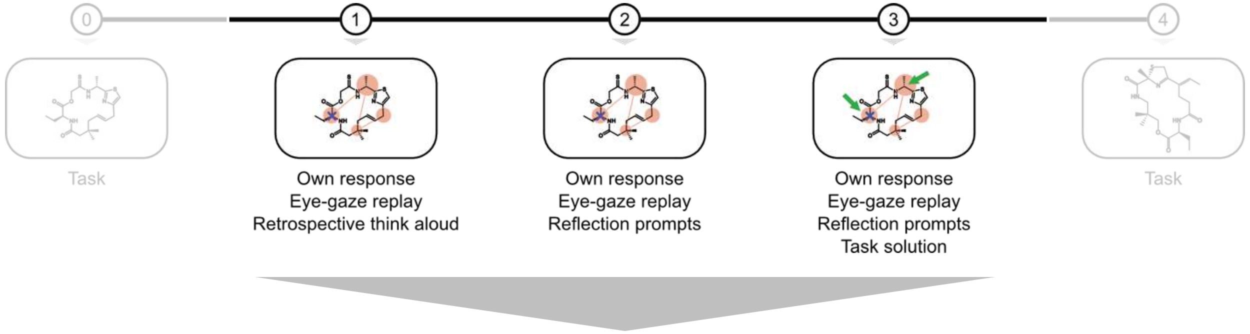
Langner & Graulich 2024

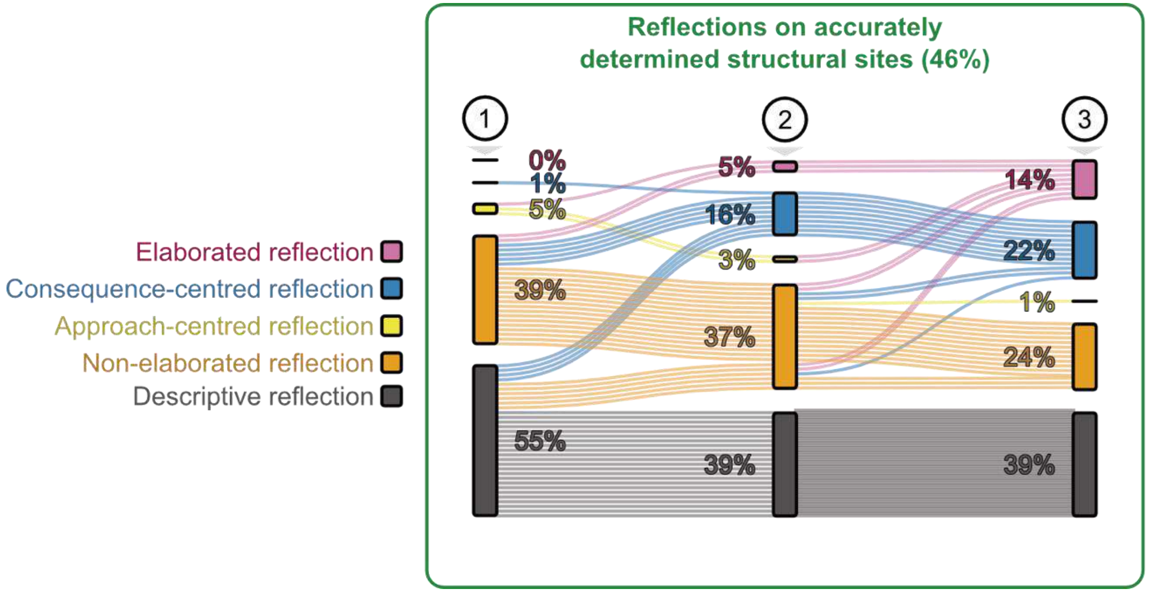
Scientific expertise development



Langner & Graulich 2024

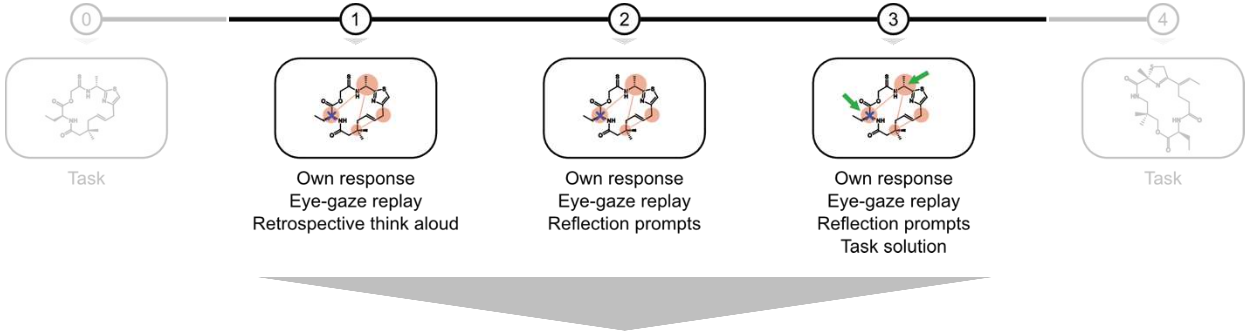
SCIENTIFIC EXPERTISE DEVELOPMENT

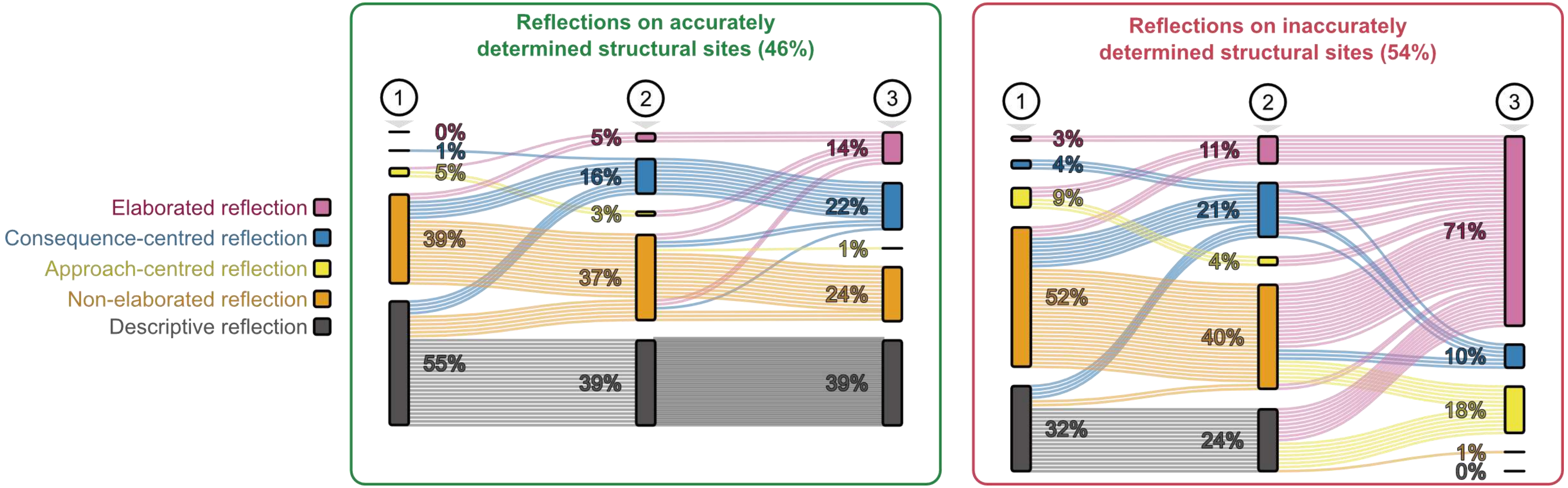




Langner & Graulich 2024

SCIENTIFIC EXPERTISE DEVELOPMENT





Langner & Graulich 2024

SCIENTIFIC EXPERTISE DEVELOPMENT

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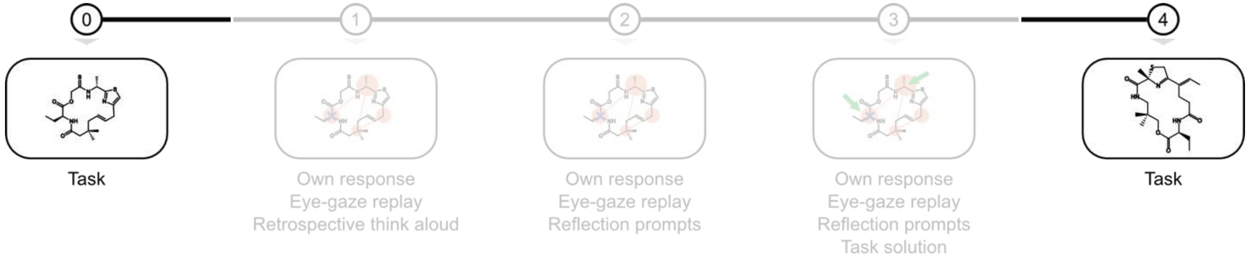

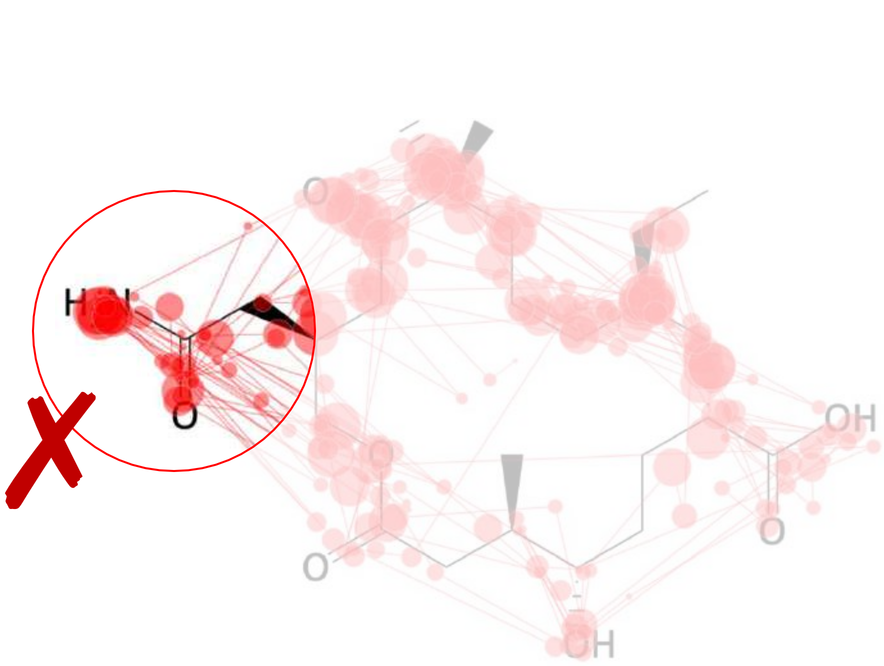

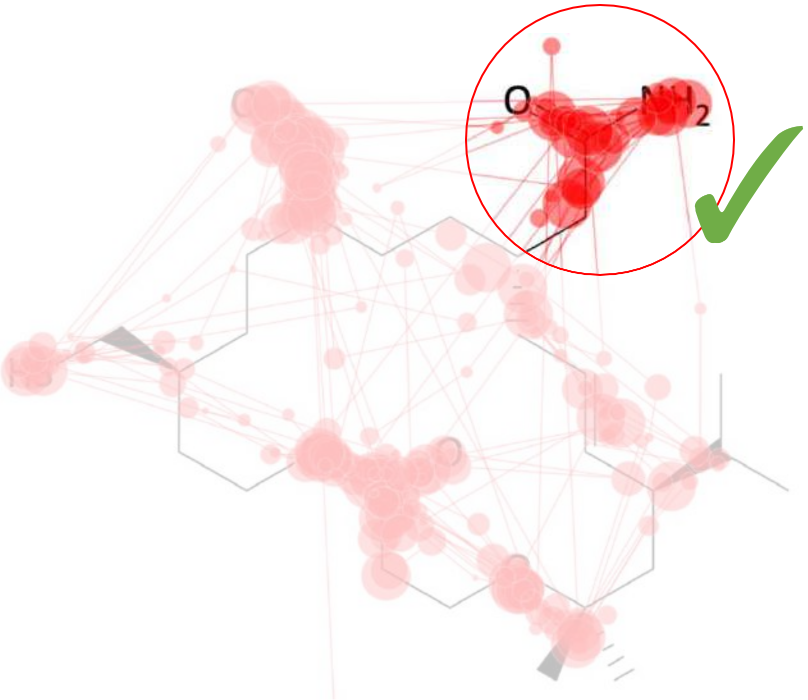

SCIENTIFIC EXPERTISE DEVELOPMENT

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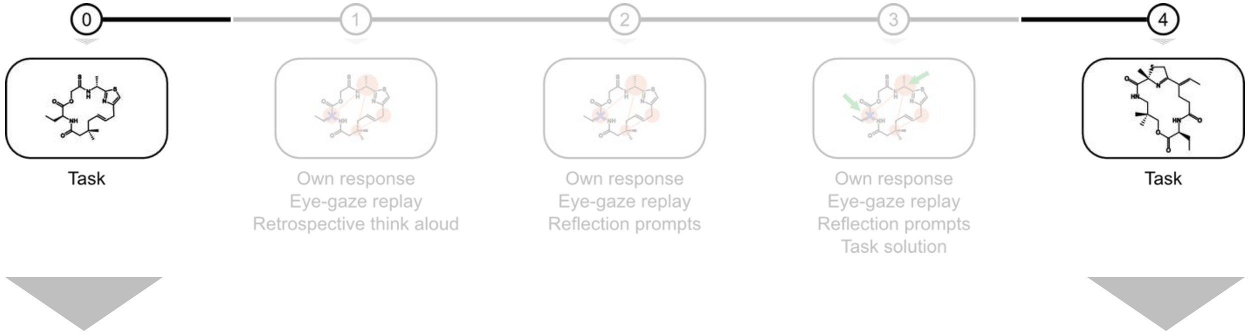
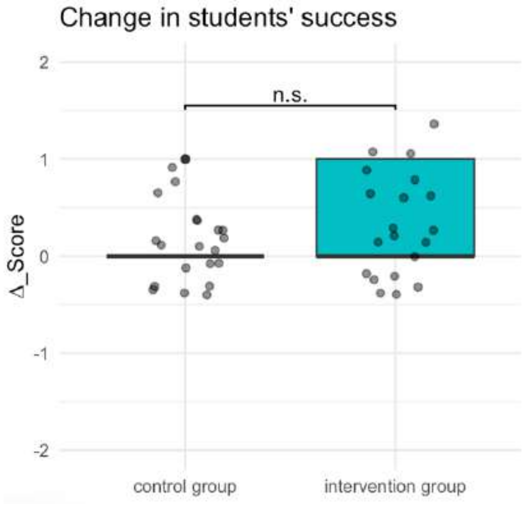


The eye-gaze-augmented retrospective…



…did **not** influence students' success.

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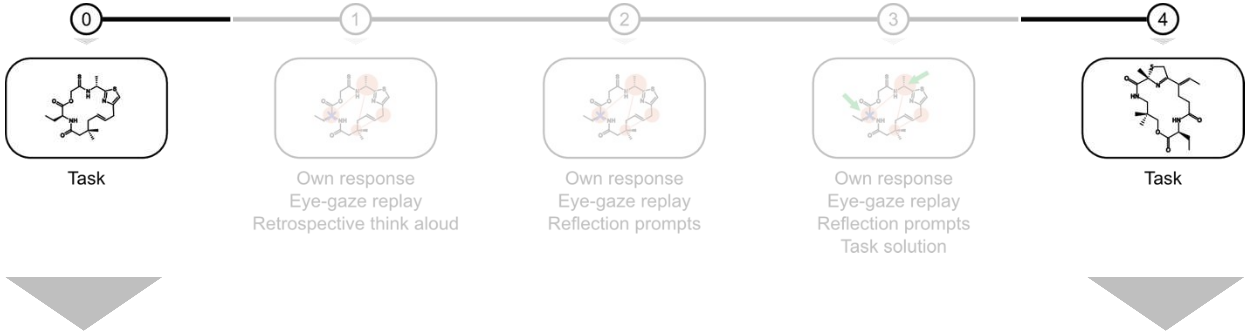
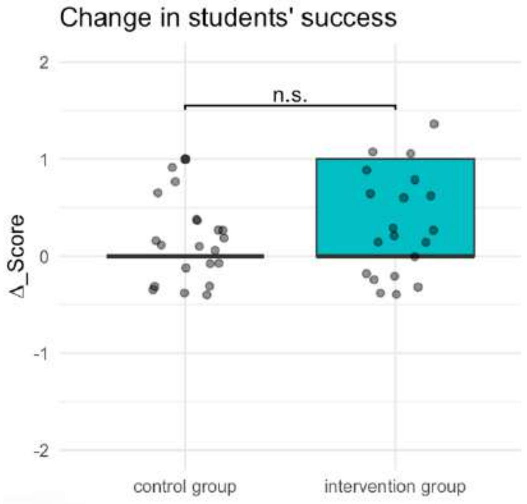
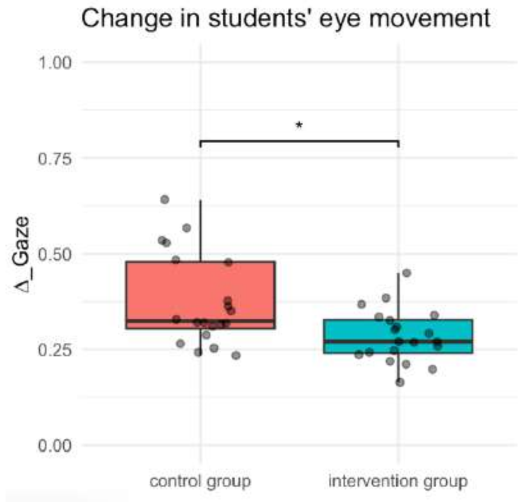
SCIENTIFIC EXPERTISE DEVELOPMENT



The eye-gaze-augmented retrospective…

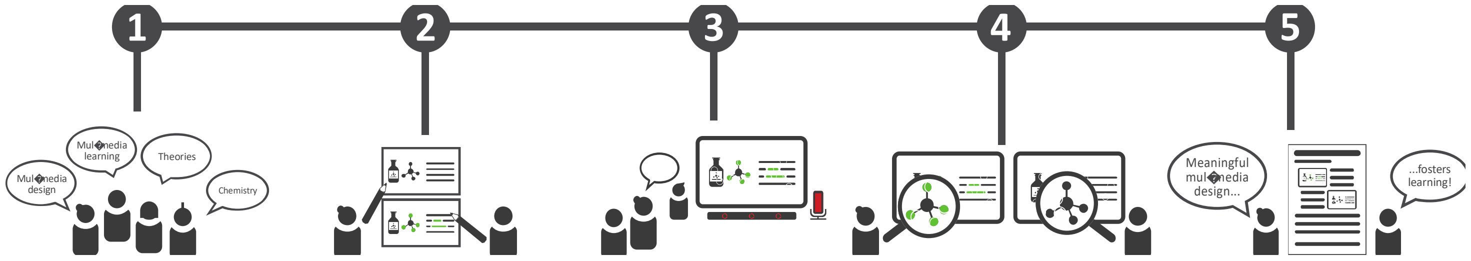


…did **not** influence students' success.

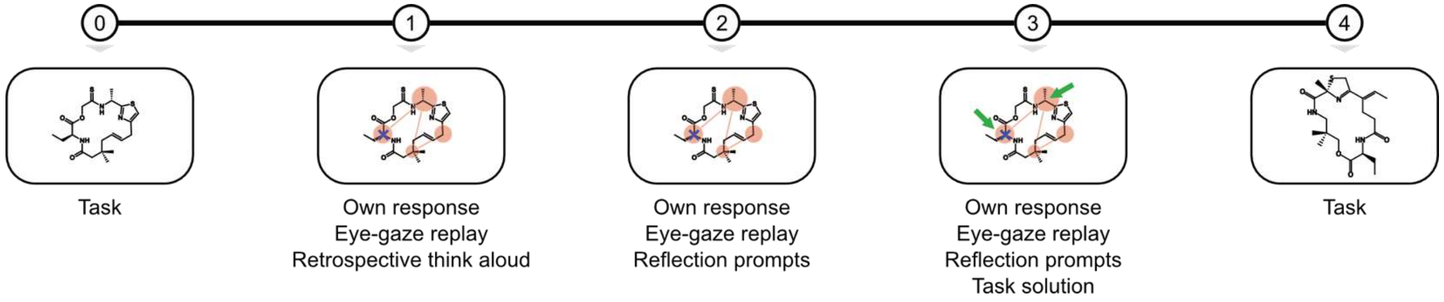


…stimulated more **consistent eye-movements**.

CONCLUSION



Eye-tracking isn't just a diagnostic tool; it can also serve as a **feedback tool**.



THANK YOU!

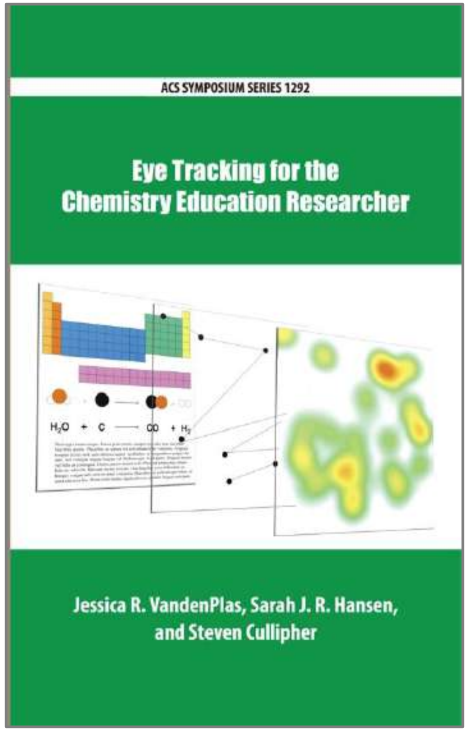
Do you have questions?

What are your thoughts?

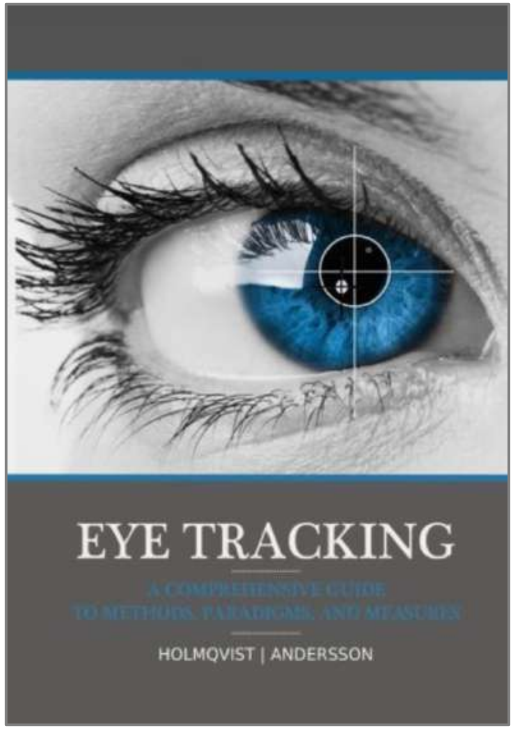
What should (chemistry education) eye-tracking research focus on?

ADDITIONAL SLIDES

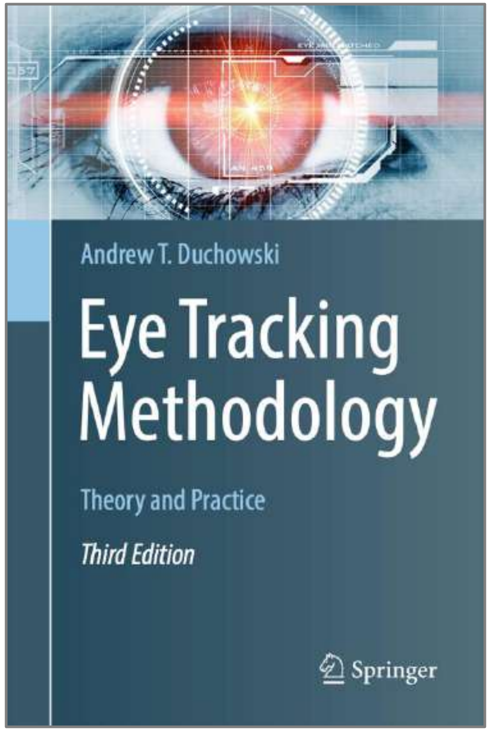
LITERATURE RECOMMENDATIONS



Eye-Tracking for Chemistry Education Researcher



Eye-Tracking Guide



Eye-Tracking Guide

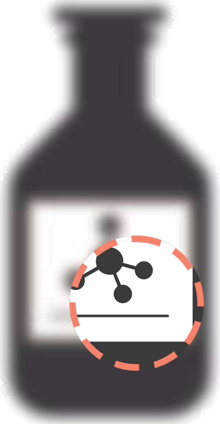
DATA COLLECTION

Screen-based

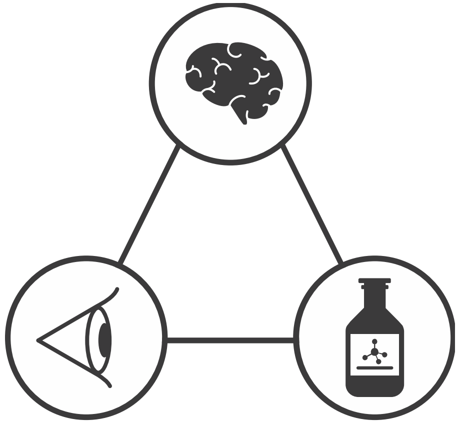
VR-Eye-Tracking

Mobile

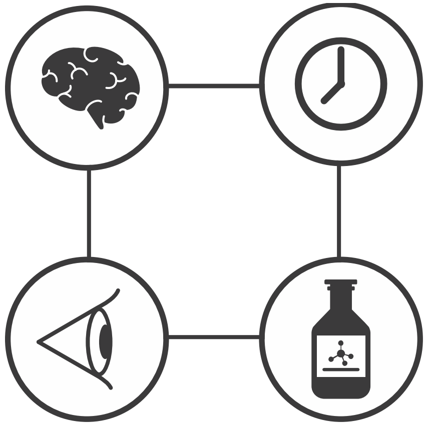
ASSUMPTIONS



Relevant information in gaze center



Immediacy assumption



Eye-mind assumption

Covert & overt attention directed to the same stimulus

Just & Carpenter 1980, Land & Tatler 2009, Duchowski 2017

VISUAL BEHAVIOR… IN VECTOR FIELD PLOTS

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **14,** 010116 (2018)

Instruction-based clinical eye-tracking study on the visual interpretation of divergence: How do students look at vector field plots?

P. Klein,[1,*] J. Viiri,[2] S. Mozaffari,[3] A. Dengel,[3,4] and J. Kuhn[1]

[1]*Department of Physics, Physics Education Research Group, University of Kaiserslautern, Erwin-Schrödinger-Strasse 46, 67663 Kaiserslautern, Germany*

[2]*Department of Teacher Education, University of Jyväskylä, 40014 Jyväskylä, Finland*

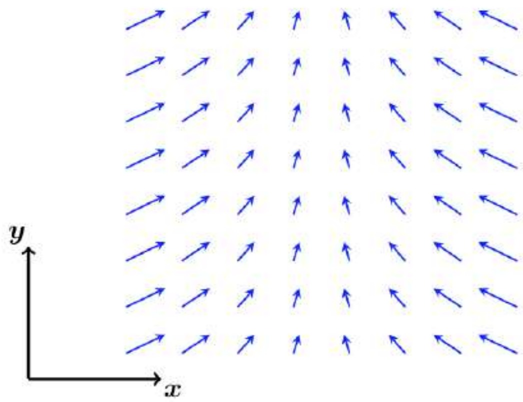
[3]*Smart Data & Knowledge Services, German Research Center for Artificial Intelligence, Trippstadter Strasse, 122, 67663 Kaiserslautern, Germany*

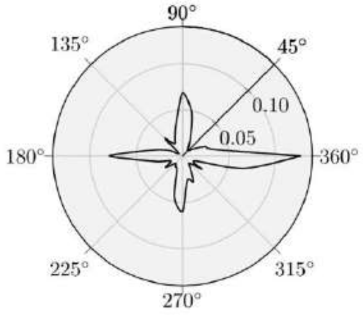
[4]*Computer Science Department, University of Kaiserslautern, Erwin-Schrödinger-Strasse 46, 67663 Kaiserslautern, Germany*

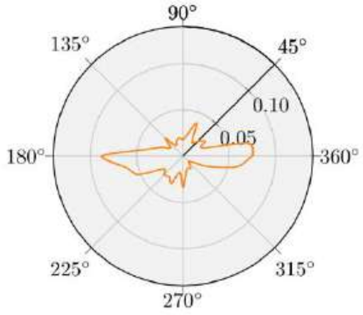
(Received 13 November 2017; published 28 March 2018)

Relating mathematical concepts to graphical representations is a challenging task for students. In this paper, we introduce two visual strategies to qualitatively interpret the divergence of graphical vector field representations. One strategy is based on the graphical interpretation of partial derivatives, while the other is based on the flux concept. We test the effectiveness of both strategies in an instruction-based eye-tracking study with $N = 41$ physics majors. We found that students' performance improved when both strategies were introduced (74% correct) instead of only one strategy (64% correct), and students performed best when they were free to choose between the two strategies (88% correct). This finding supports the idea of introducing multiple representations of a physical concept to foster student understanding. Relevant eye-tracking measures demonstrate that both strategies imply different visual processing of the vector field plots, therefore reflecting conceptual differences between the strategies. Advanced analysis methods further reveal significant differences in eye movements between the best and worst performing students. For instance, the best students performed predominantly horizontal and vertical saccades, indicating correct interpretation of partial derivatives. They also focused on smaller regions when they balanced positive and negative flux. This mixed-method research leads to new insights into student visual processing of vector field representations, highlights the advantages and limitations of eye-tracking methodologies in this context, and discusses implications for teaching and for future research. The introduction of saccadic direction analysis expands traditional methods, and shows the potential to discover new insights into student understanding and learning difficulties.

Interpret the divergence of this vector field.



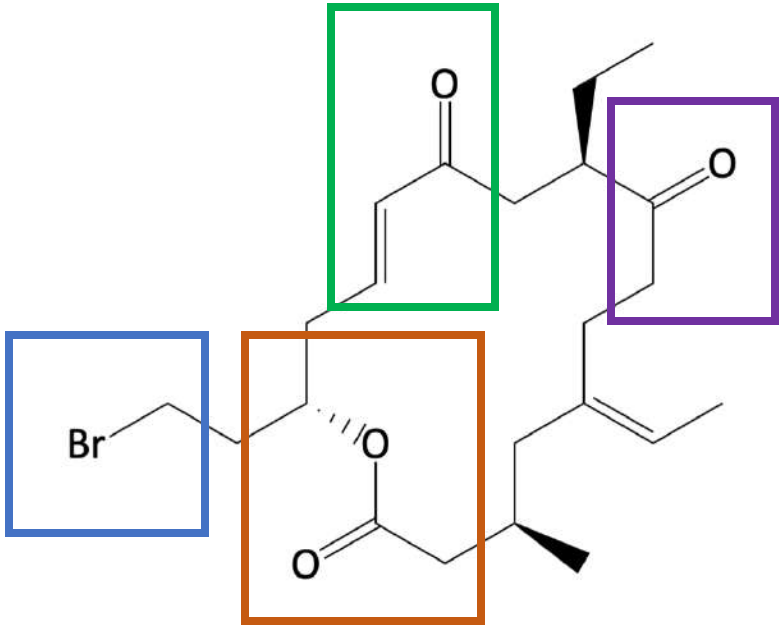




best performer | worst performer

Klein *et al.* 2018

DATA ANALYSIS



Areas of Interest (AOI)

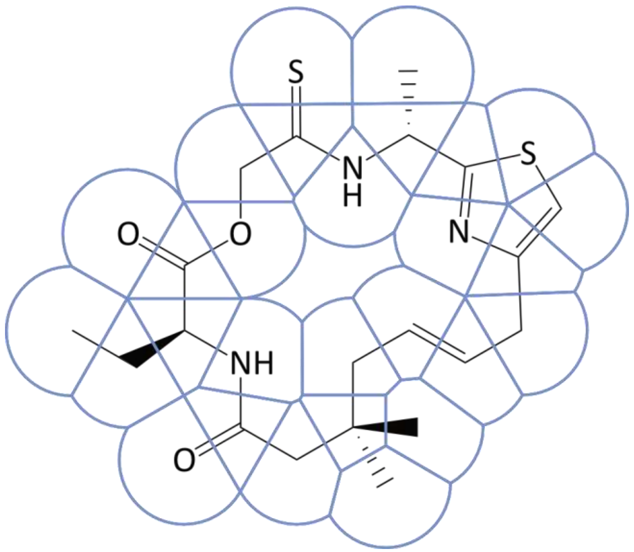
Number of fixations
Fixation duration
Gaze proportion
Gaze path
Transition
Revisits
Time to first revisit
First five fixations
Time to first fixaiton
Time of first visit
Dwell time
Saccade angle
Pupil dilation
Blinks
...

Metrics

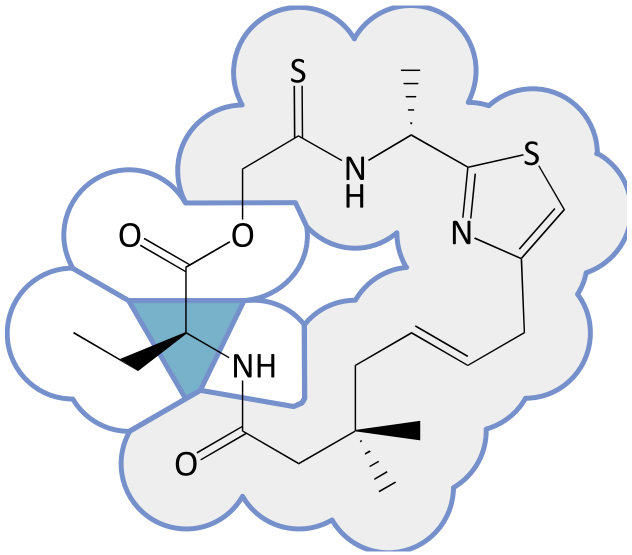
Für weitere Informationen siehe Holmqvist *et al.* 2011

DATA PREPARATION

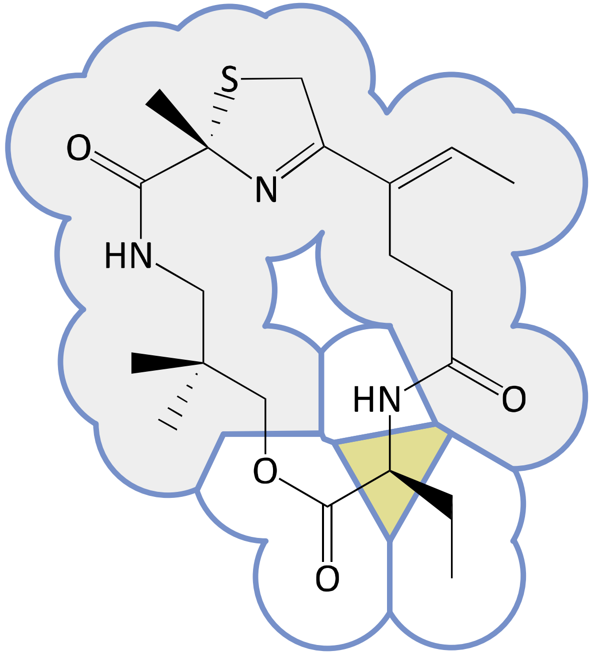
Defining Areas of interest (AOIs)



Limited-radius
Voronoi tesselation



Task 1



Task 2

Langner *et al.* (2025)

DATA INTERPRETATION

Fixation duration:
- Attention (Desjarlais 2017)
- Information processing (Clinton 2017)
- Difficultiy (Holmqvist *et al.* 2011)
- Organisation process (Alemdag & Cagiltay 2018)
- Cognitive load (Tang & Pienta 2012)
- Comprehension process (Cullipher *et al.* 2018)
- Task complexity (Cullipher *et al.* 2018)
- Expertise level (Baluyut & Holme 2019)
- Layout evaluation (Gegenfurtner 2011)
- Distractors (Duchowski 2002)
- Interest (Desjarlais 2017)
- …

Transitions:
- Visual attention distribution (Richter & Scheiter 2019)
- Information processing (Desjarlais 2017)
- Working memory capacity(Holmqvist *et al.* 2011)
- Integration process (Alemdag & Cagiltay 2018)
- Chunking (Holmqvist *et al.* 2011)
- Comprehension process (Scheiter & Eitel 2017)
- Effort of information integration (Mason et al. 2013)
- prior knowledge (Scheiter & Eitel 2017)
- Expertise level (Topczewski *et al.* 2017)
- Transfer performance (Scheiter & Eitel 2017)
- Success (Krebs *et al.* 2019)
- Layout evaluation (Holmqvist *et al.* 2011)
- Importance of information (Holmqvist *et al.* 2011)
- task complexity (Holmqvist *et al.* 2011)
- …

ET IN CHEMISTRY EDUCATION RESEARCH

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Chemistry Education Research

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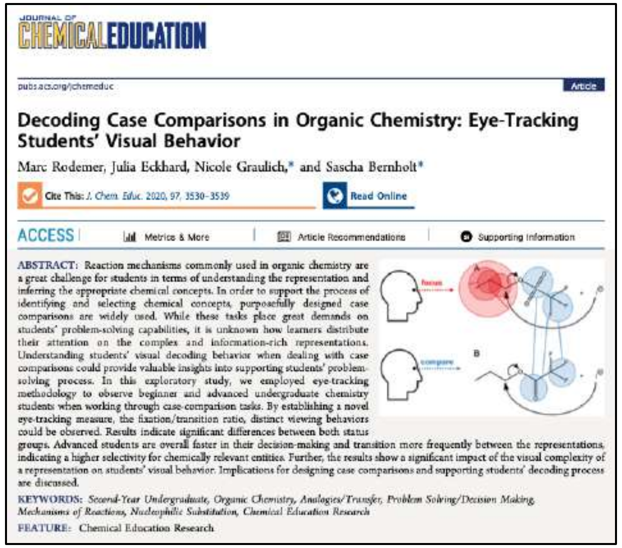
Diagnosis & Assessment

Problem-solving strategies | **Expertise comparisons** | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability


JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc Article

Decoding Case Comparisons in Organic Chemistry: Eye-Tracking Students' Visual Behavior

Marc Rodemer, Julia Eckhard, Nicole Graulich,* and Sascha Bernholt*

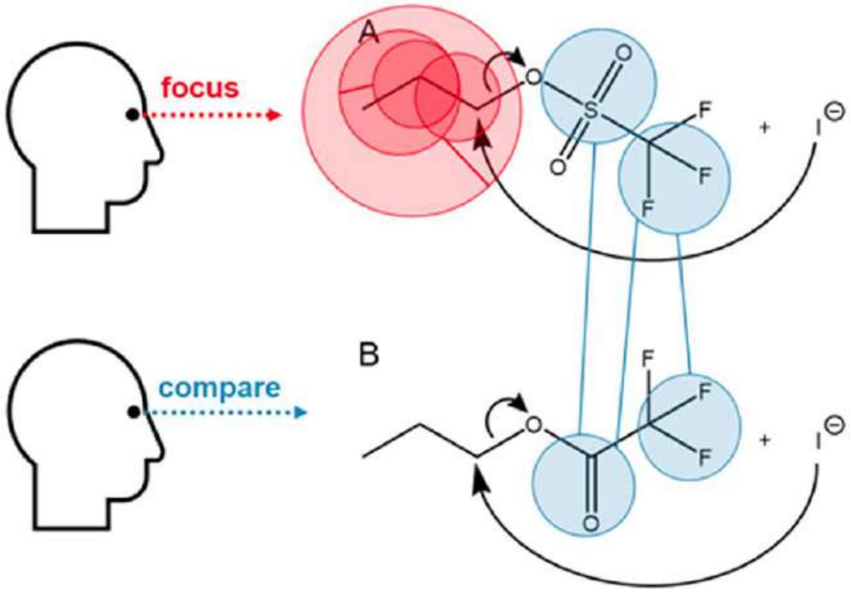
Cite This: *J. Chem. Educ.* 2020, 97, 3530–3539 Read Online

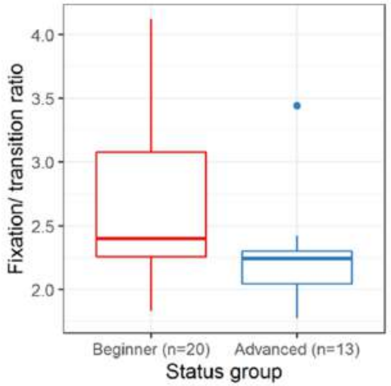
ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Reaction mechanisms commonly used in organic chemistry are a great challenge for students in terms of understanding the representation and inferring the appropriate chemical concepts. In order to support the process of identifying and selecting chemical concepts, purposefully designed case comparisons are widely used. While these tasks place great demands on students' problem-solving capabilities, it is unknown how learners distribute their attention on the complex and information-rich representations. Understanding students' visual decoding behavior when dealing with case comparisons could provide valuable insights into supporting students' problem-solving process. In this exploratory study, we employed eye-tracking methodology to observe beginner and advanced undergraduate chemistry students when working through case-comparison tasks. By establishing a novel eye-tracking measure, the fixation/transition ratio, distinct viewing behaviors could be observed. Results indicate significant differences between both status groups. Advanced students are overall faster in their decision-making and transition more frequently between the representations, indicating a higher selectivity for chemically relevant entities. Further, the results show a significant impact of the visual complexity of a representation on students' visual behavior. Implications for designing case comparisons and supporting students' decoding process are discussed.

KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, Analogies/Transfer, Problem Solving/Decision Making, Mechanisms of Reactions, Nucleophilic Substitution, Chemical Education Research*

FEATURE: Chemical Education Research



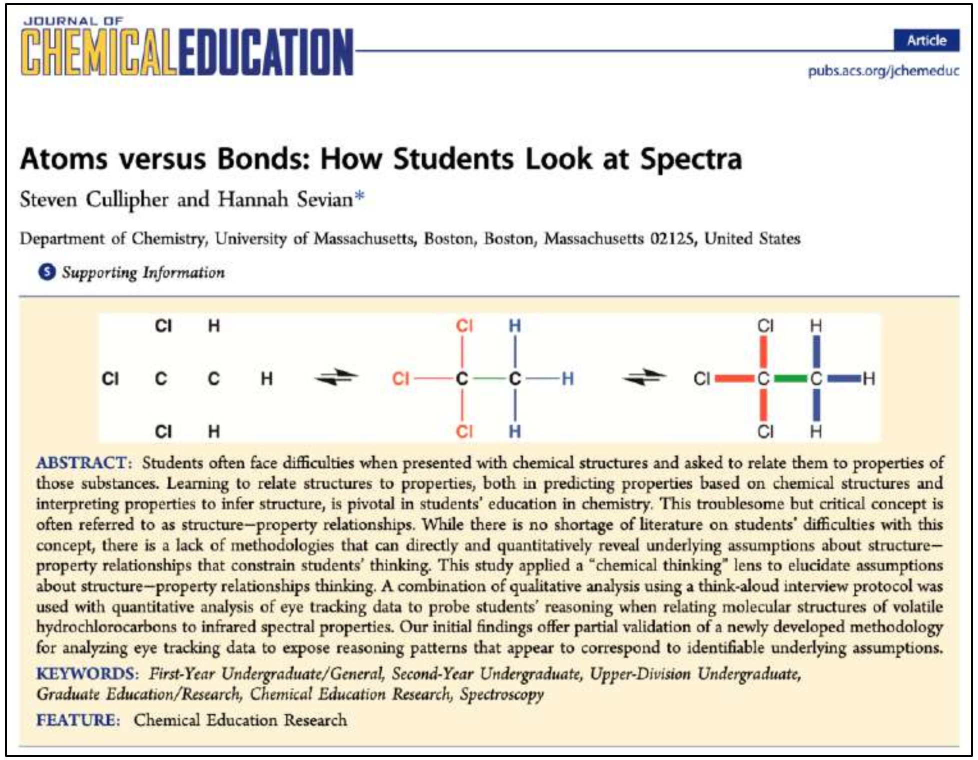


Beginner students exhibit **more focused behavior**.

ET IN CER

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | Evaluation of learning materials | Cognitive demand | Predictability



JOURNAL OF CHEMICAL EDUCATION
Article
pubs.acs.org/jchemeduc

Atoms versus Bonds: How Students Look at Spectra

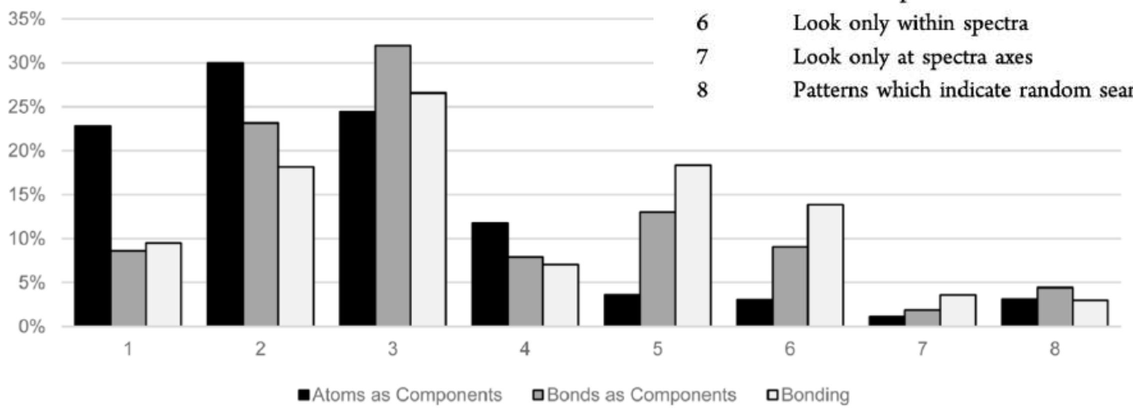
Steven Cullipher and Hannah Sevian*
Department of Chemistry, University of Massachusetts, Boston, Boston, Massachusetts 02125, United States

Supporting Information

ABSTRACT: Students often face difficulties when presented with chemical structures and asked to relate them to properties of those substances. Learning to relate structures to properties, both in predicting properties based on chemical structures and interpreting properties to infer structure, is pivotal in students' education in chemistry. This troublesome but critical concept is often referred to as structure–property relationships. While there is no shortage of literature on students' difficulties with this concept, there is a lack of methodologies that can directly and quantitatively reveal underlying assumptions about structure–property relationships that constrain students' thinking. This study applied a "chemical thinking" lens to elucidate assumptions about structure–property relationships thinking. A combination of qualitative analysis using a think-aloud interview protocol was used with quantitative analysis of eye tracking data to probe students' reasoning when relating molecular structures of volatile hydrochlorocarbons to infrared spectral properties. Our initial findings offer partial validation of a newly developed methodology for analyzing eye tracking data to expose reasoning patterns that appear to correspond to identifiable underlying assumptions.

KEYWORDS: *First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, Graduate Education/Research, Chemical Education Research, Spectroscopy*
FEATURE: Chemical Education Research

Pattern	Description
1	Only look at molecular features
2	Return to the question
3	Look at molecular features and spectra
4	Look at molecule, spectrum, and axis
5	Look at a spectrum and an axis
6	Look only within spectra
7	Look only at spectra axes
8	Patterns which indicate random searching



Underlying assumptions show **different gaze patterns**.

ET IN CER

Diagnosis & Assessment

Problem-solving strategies | Expertise comparisons | Usage of representations | **Evaluation of learning materials** | Cognitive demand | Predictability

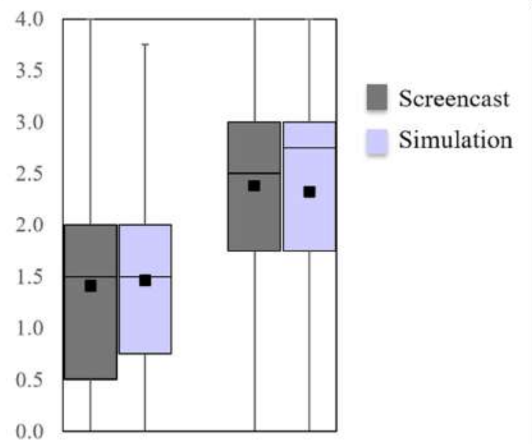


Fig. 2 Box plot of students' pretest and follow-up scores on a 4-point scale by treatment. Note: average scores are represented by black squares

No differences in learning gains while using instructor-led screencasts vs. simulations.

But eye-tracking data revealed:
- screencasts may allow students to **better integrate different levels of Johnstone triangle**
- screencasts students may have **lower cognitive demand**

Recommendation: Use screencasts to introduce simulations

DISCUSSION

Pros:

- objective, non-invasive sensor
- real-time data
- rich and more detailed data
- unique (visual attention)

Cons:

- expensive
- time-consuming
- challenging

Thoughts:

- Can be replaced by some methods (e.g., pupil dilation vs. questionnaire), but not all
- Quality of research various highly
- Every ET-research is also methodology research how to use ET in CER
- Potential not exhausted