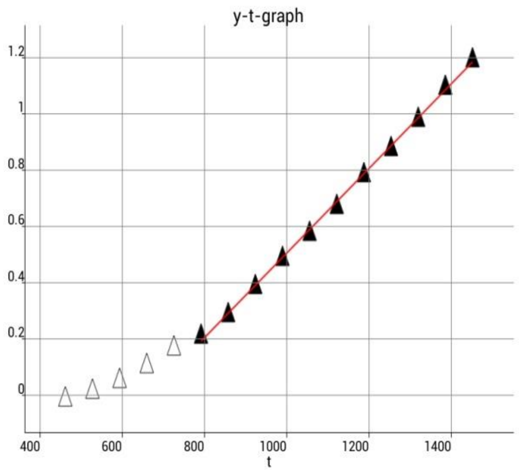
Visualizing and Analyzing MERs in Physics Education

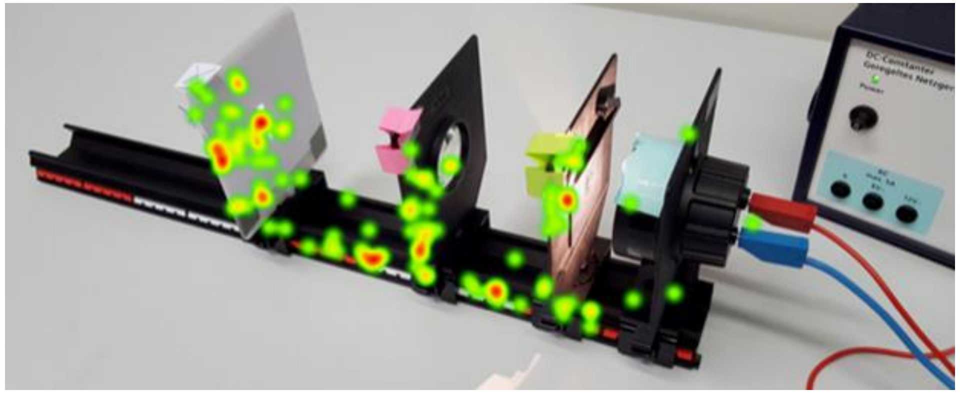
From Augmented Reality, Eye Tracking and Artificial Intelligence

Stefan Küchemann & Jochen Kuhn, TUK/PERG

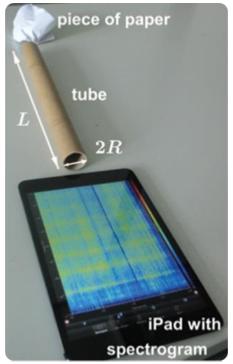
Outline

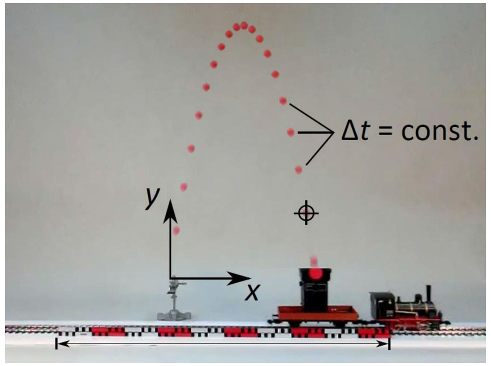
1. Visualizing scientific phenomena: basic ideas and theoretical links (JK)
2. Using smartphones and tablets as mobile Mini-Labs (JK)
3. Using technology to virtually augment our real world (JK)
4. Assessing Learning: Paper-based, process level, AI-Algorithms (SK)
5. Summary and outlook (SK)



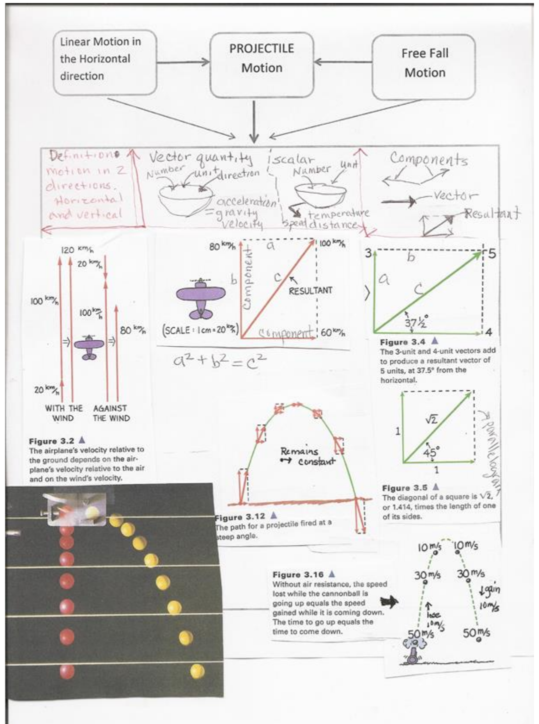


Visualizing scientific phenomena: basic ideas and theoretical links





Basic ideas:
- Combining **real** experiments **with virtual** information **for inquiry-based learning** in physics
- Using **(internal) sensors** of (everyday) devices to detect scientific variables (of daily phenomena)
- Using Apps to **visualize measured variables**



Theoretical links: Learning with Multiple (External) Representations (MER
- important role of competent handling of MER for STEM education (e.g. Verschaffel et al. 2010) – considering their design opportunities and different functions (DeFT; Ainsworth, 2006)
- Representational competence as domain-specific prerequisite for conceptual understanding, reasoning, and problem solving(e.g. Rau, 2017)
- BUT: learners of each age often struggle with MER (Scheid et al., 2019).

⇨ Studying selection, organization and integration processes in learning and problem solving with MER through multimedia (CTML; Mayer, 2014).

⇨ Varying cognitive load to affect learning processes (CLT; Sweller & Chandler, 1991)

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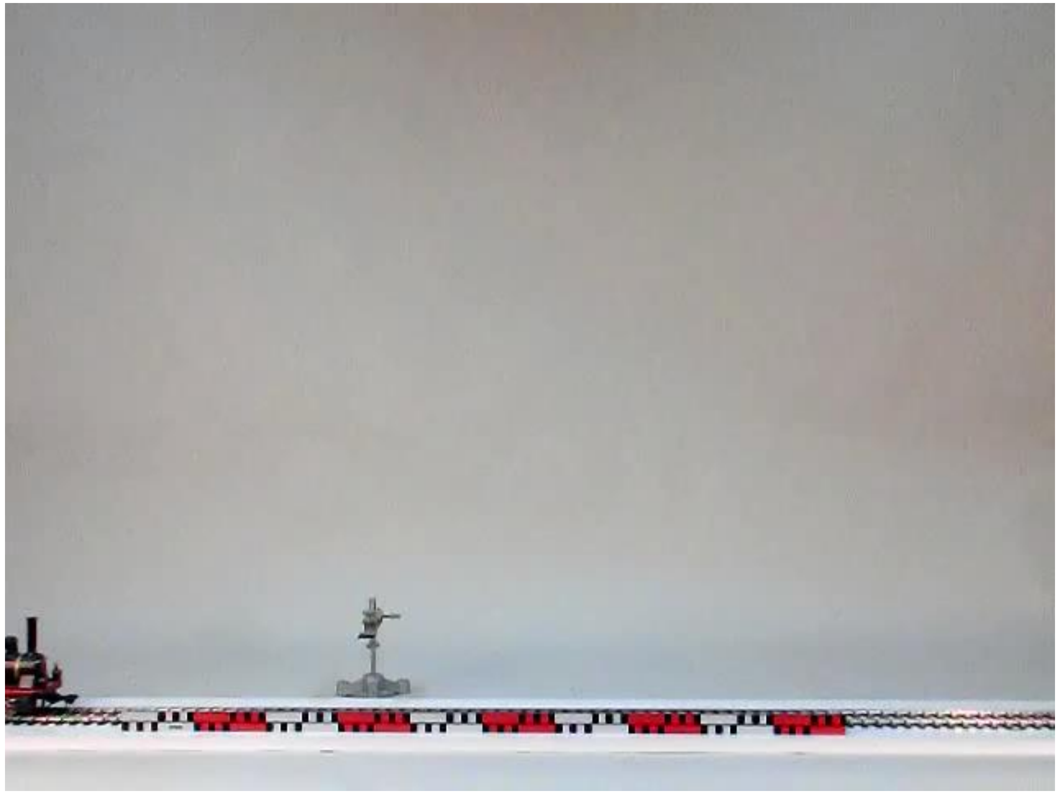
Using smartphones and tablets as mobile Mini-Labs

Examples and possibilities of dealing with abstractness

Smartphones as mobile Mini-Lab: Mechanics (Camera; Video Motion Analysis)



Video Motion Analysis

- Contactless acquisition of position-time data of several objects (primary data)

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Smartphones as mobile Mini-Lab: Mechanics (Camera; Video Motion Analysis)

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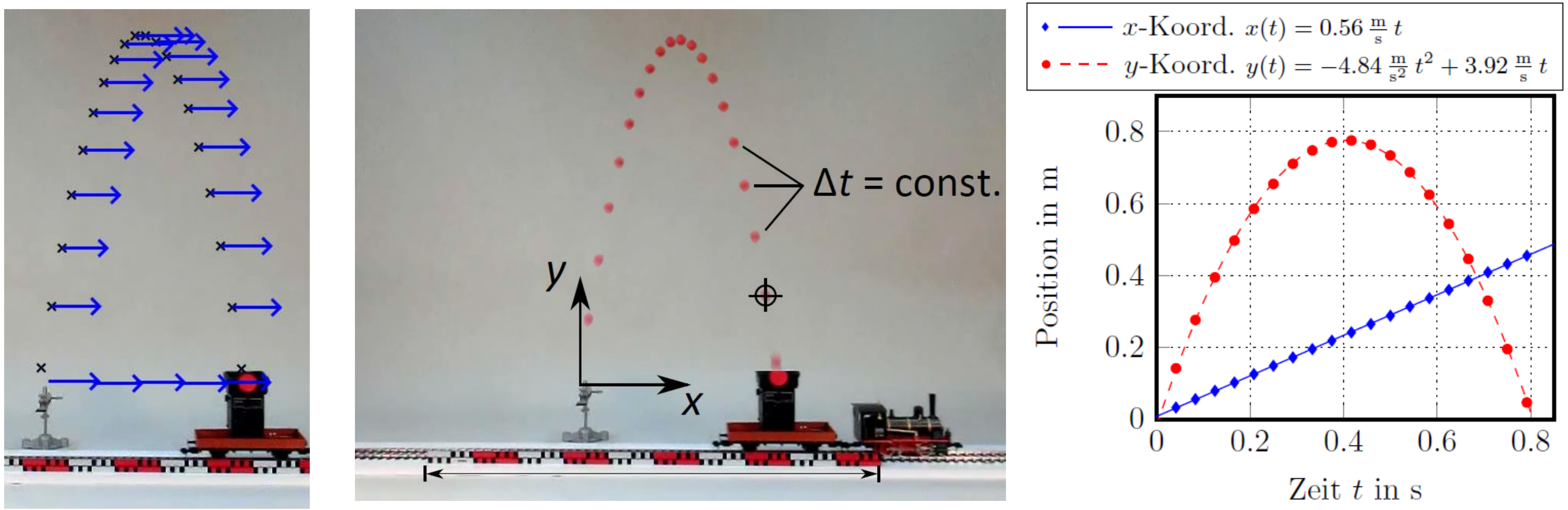

Video Motion Analysis

- Contact-free acquisition of position-time data of several objects (primary data)
- Calculation of further physical quantities (velocity, energy)
- Various MERs and analysis options of the measurement data with suitable app (Vernier Videophysics)

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Smartphones as mobile Mini-Labs: Examples

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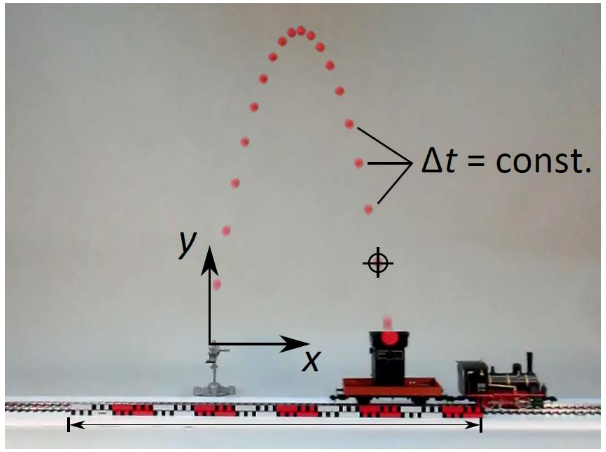
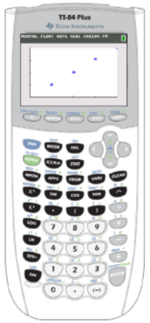
Inquiry-based learning studies: Learning with mobile devices vs. "traditional" learning

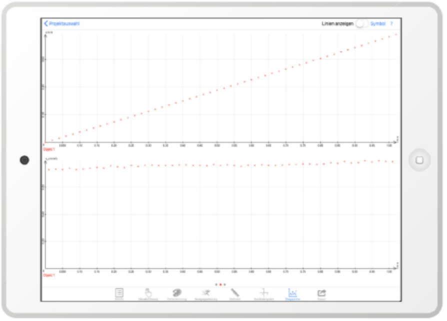
Materials and methods:



- 6 experimental/randomized field trials in acoustics and mechanics with experimental and control groups in pre-post (follow up) test design
- Secondary schools and introductory university physics courses
- In total: $N > 650$
- Cognitive (cognitive load, conceptual understanding, representational competence) and affective (interest/motivation, curiosity) measures

Results:





- Significant differences between control and experimental groups in…
  - …subject-related interest and motivation
  - …subject-related curiosity of lower-performing learners
  - …conceptual understanding with mobile video motion analysis
- Reduction of learning-irrelevant cognitive load through mobile video analysis
  => causal connection with promotion of concept understanding and emotion

Becker, et al. (2020), *Learn. Instr. 69* (2020), 101350.
Becker, et al.(2020), *ZfDN 26* (2020), 123-142
Hochberg, Kuhn & Müller (2018), *J Sci Educ Technol,27* (5), 385-403.
Hochberg et al. (2020), *J Sci Educ Technol, 29* (2), 303-317
Klein, P., Müller, A. & Kuhn, J. (2017). *Phys. Rev. Phys. Educ. Res. 13*, 010132
Kuhn & Vogt (2015), Basingstoke, UK: Palgrave Macmillan, *pp. 253-269.*

Smartphones as mobile Mini-Labs: dealing with abstractness

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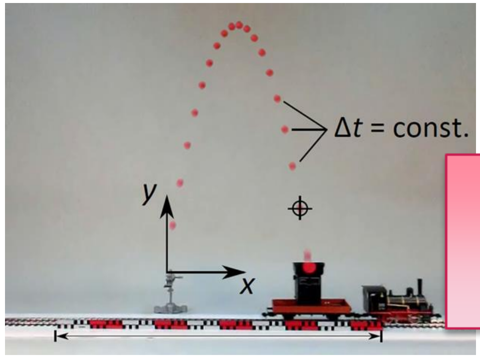
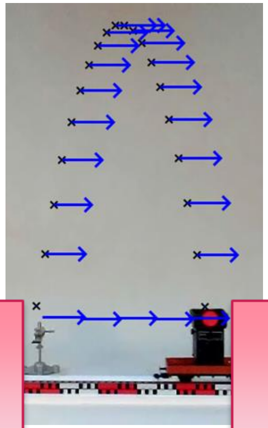
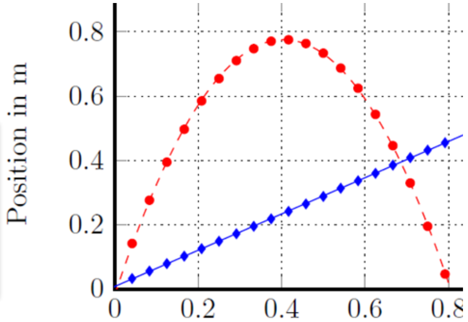






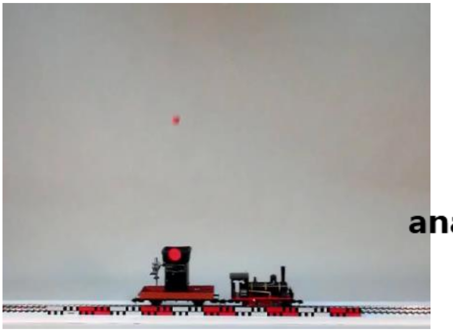
visual-Graphical Representations
picture, graph,…

verbal-textual representations
spoken or written text

actional-operational representations
experiment, manipulatives,…

Representation

symbolic-mathematical representations
formula, equation,…



analog

symbolic

x-Koord. $x(t) = 0.56\,\frac{\mathrm{m}}{\mathrm{s}}\,t$

y-Koord. $y(t) = -4.84\,\frac{\mathrm{m}}{\mathrm{s}^2}\,t^2 + 3.92\,\frac{\mathrm{m}}{\mathrm{s}}\,t$

science phenomenon

conceptual knowldge

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Using technology to virtually augment our real world

Multimedia Learning with head-mounted AR environments

MARVEL SPIDER-MAN

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What is Augmented Reality (AR)?

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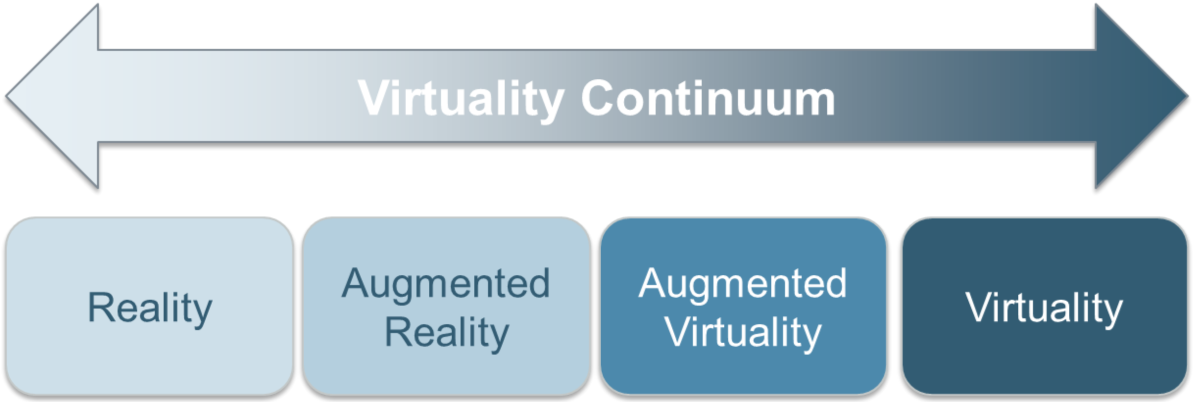
AR must have the following three characteristics:

- Combining real and virtual
- Interactive in real time
- Registered in 3-D

R.T. Azuma, A Survey of Augmented Reality, Presence-Teleoperators and Virtual Environments, Vol. 6, No. 4, pp. 355-385, 1997

Different Shadings of Reality

- **Mixed Reality** involves the merging of real and virtual worlds somewhere along the '**virtuality continuum**', which connects completely real environments to completely virtual ones.



P. Milgram and F. Kishino, A Taxonomy of Mixed Reality Visual Displays, IEICE Trans. Information and Systems, vol. 77, no. 12, pp.1321-1329, 1994

Types of AR

Pokémon GO (The Pokémon Company)

- **Superimposed AR**
Standard display (hand-held,portable)

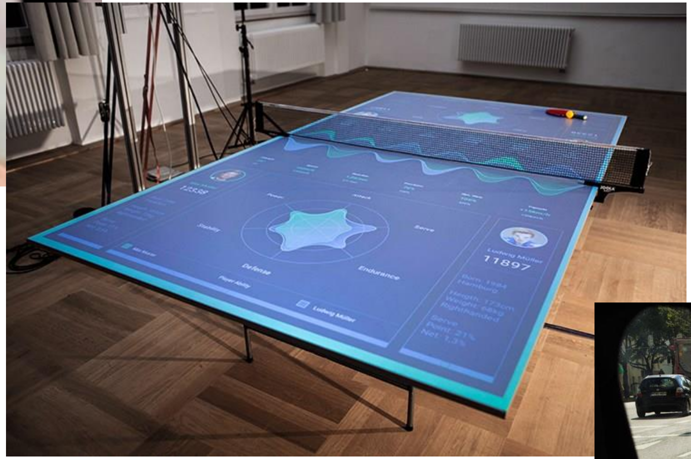
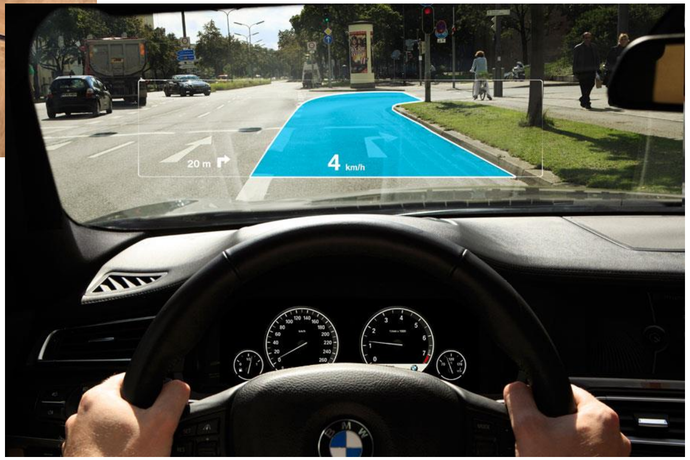


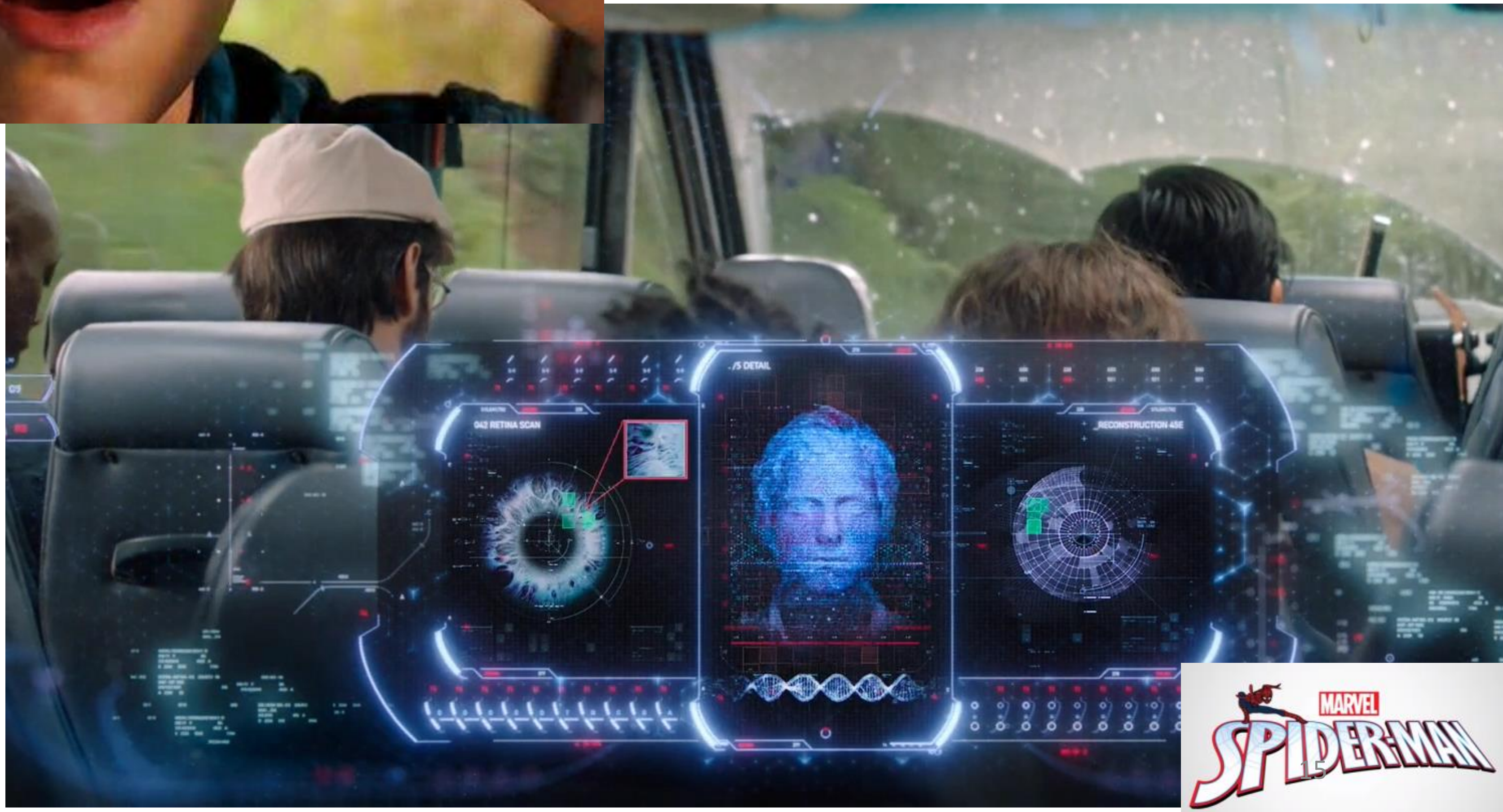
Table Tennis Trainer (Thomas Mayer)

- **Spatial AR**
Projection based display
(usually fixed position)

Head-up display (BMW)



- **See-through AR**
transparent display
(fixed, head mounted)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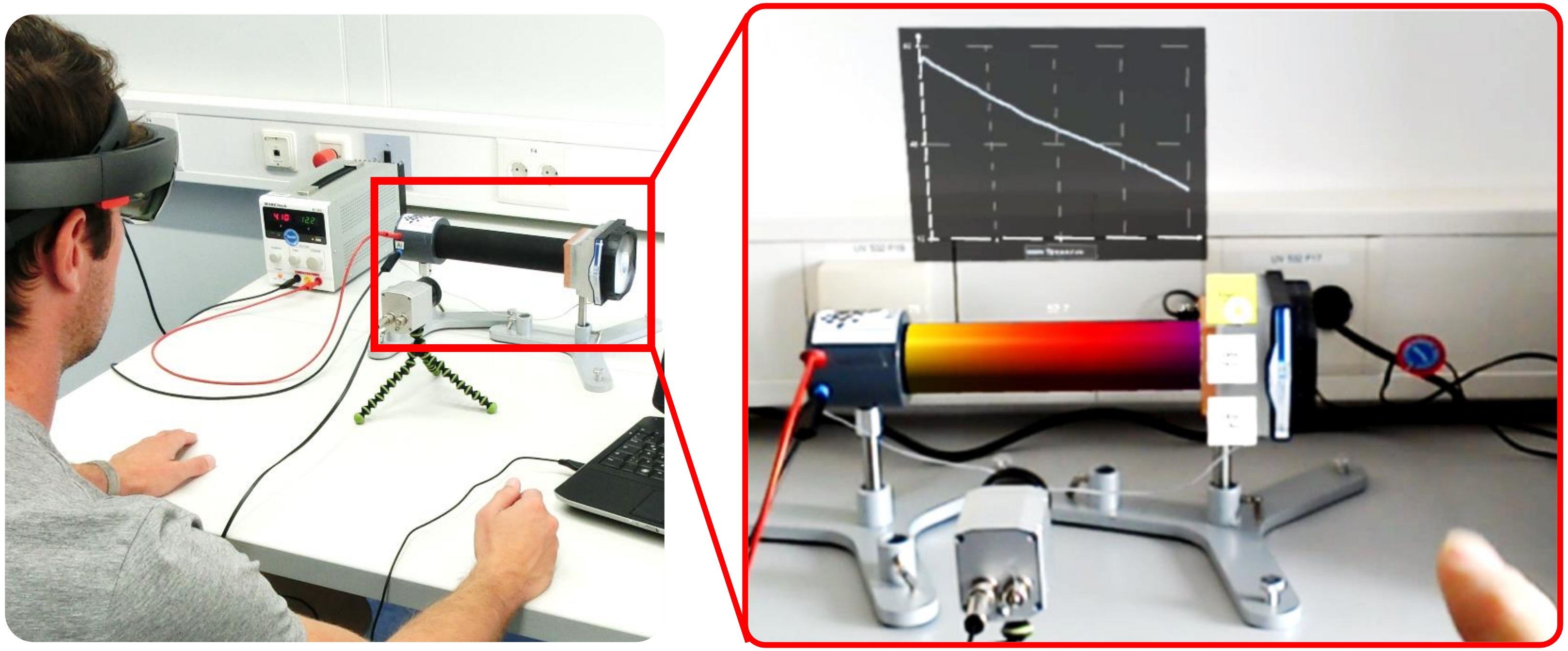
./S DETAIL
_RECONSTRUCTION 45E

Head mounted-AR environments: R&D

Heat conduction in metals



Typical experiment on heat conduction in metals in the university physics lab course at TUK

Strzys, M. P., Kapp, S., Thees, M., Klein, P., Lukowicz, P., Knierim, P., Schmidt, A. & Kuhn, J. (2018). Physics holo.lab learning experience: Using Smartglasses for Augmented Reality labwork to foster the concepts of heat conduction. *Eur. J Phys. 39* (3), 035703.

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Head mounted-AR environments: R&D

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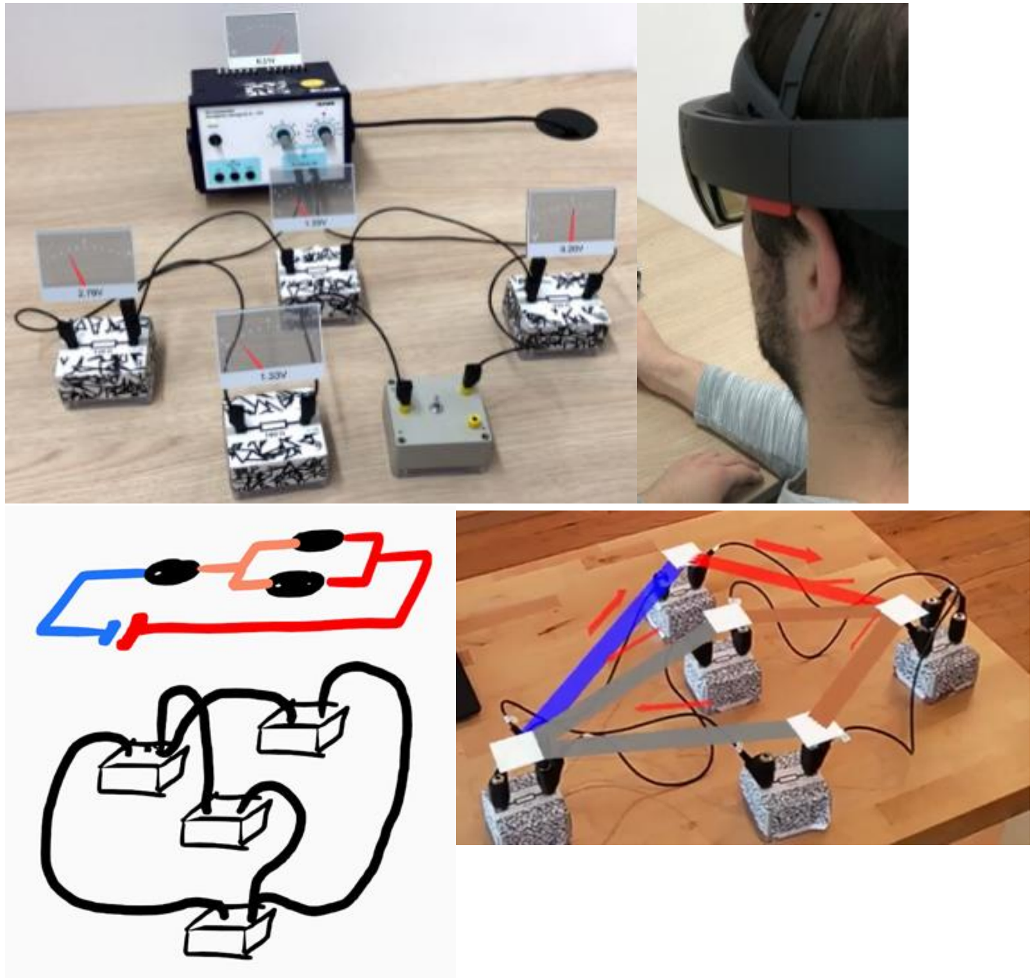
Effects of augmented reality on learning and cognitive load in university physics laboratory courses

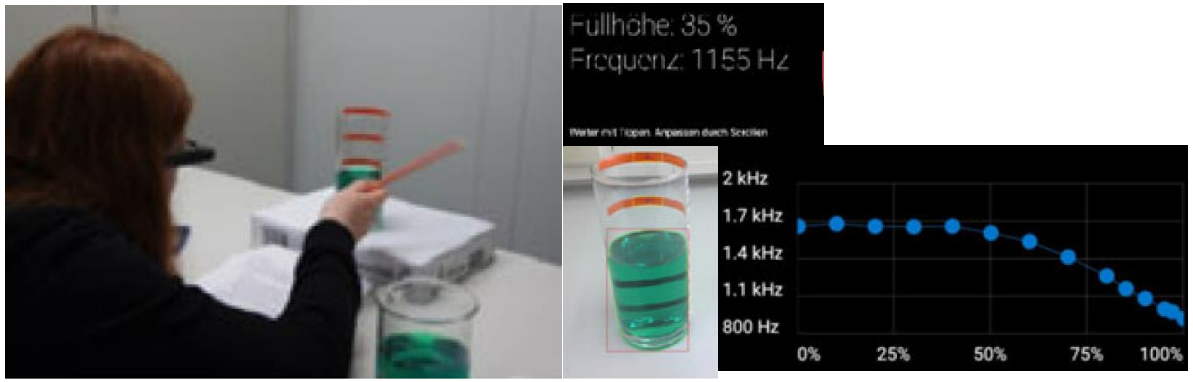
Supplementary video: View through the smartglasses

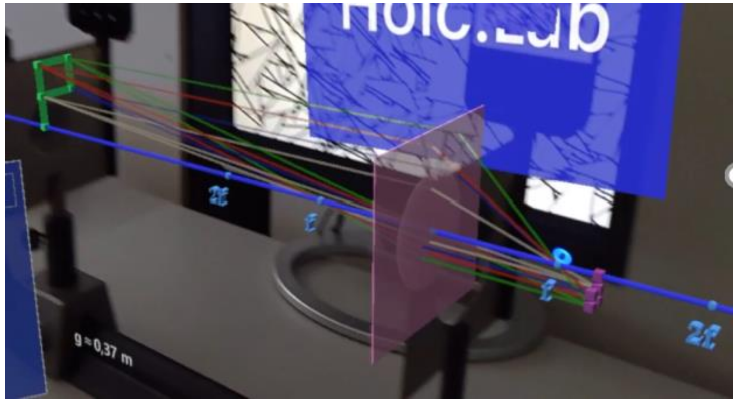
The video shows the newest version of the application for smartglasses (08/22/2019), adapted after the study was completed. The updates were technical updates and did not change the method of interaction.

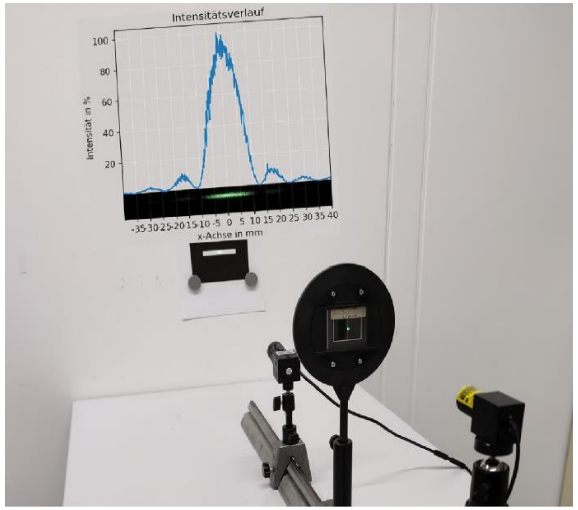
Thees, M., Kapp, S., Strzys, M. P., Beil, F., Lukowicz, P. & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. *Comp. Hum. Behav. 108* (2020), 106316.

Head mounted-AR environments: R&D









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Inquiry-based learning studies: Learning with AR vs. non-AR environment

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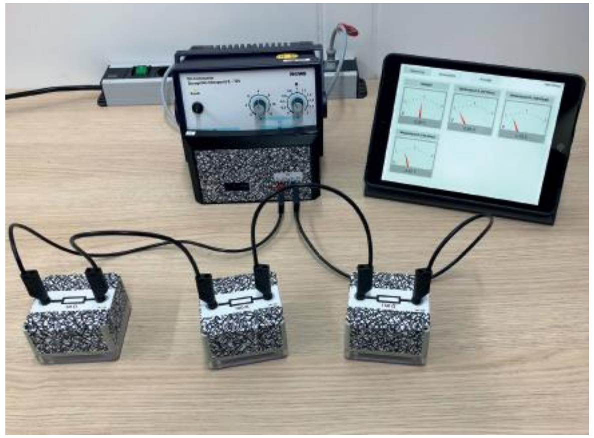
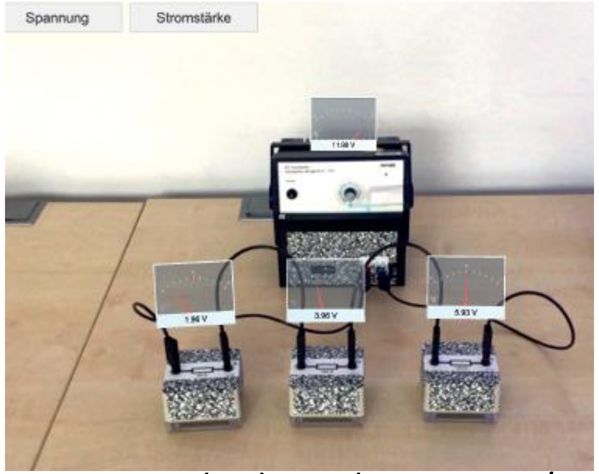

Control Group (CG): non-AR (tablet-2D; split source format)



Exp. Group (EG): AR (superimp./ see-through; integrated format)

Materials and methods:

- 5 (experimental and quasi-experimental) trials in thermodynamics and electrics with experimental and control groups in pre-post test design
- More than 250 university students (all fields)
- Cognitive (cognitive load, conceptual understanding) and affective (interest/motivation, curiosity, usability) measures
- AR (EG; superimposed/see-trough) vs. non-AR (CG; tablet-2D)

Results:

- Increase of conceptual understanding higher in EG than in CG (only superimp. AR)
- Learning-irrelevant (extraneous) cognitive load in EG lower than in CG (electric: only superimp. AR; thermodynamics: see-through AR)

Coming soon: replication study with primary students

- Additional measures of students learning process with eye-tracking

Multimedia Learning with AR environments: dealing with abstractness

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visual-Graphical Representations
picture, graph,…

verbal-textual representations
spoken or written text

actional-operational representations
experiment, manipulatives,…

Representation

symbolic-mathematical representations
formula, equation,…

$$T(x,t) = T_0 + (T_1 - T_0)\mathrm{e}^{-\alpha x}$$

analog

symbolic

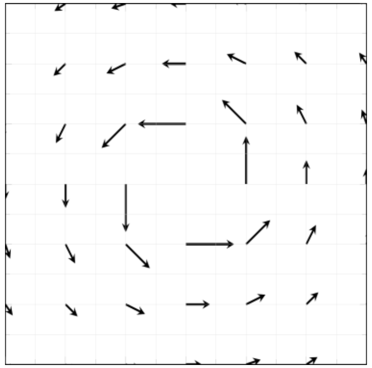
science phenomenon

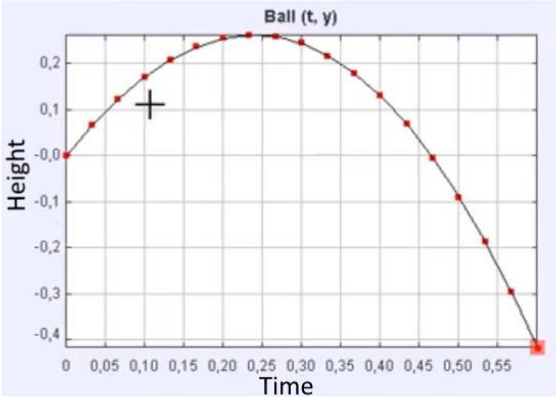
conceptual knowldge

Assessing Learning: Paper-based, process level, AI-algorithms

The trajectory of the ball follows a parabolic path

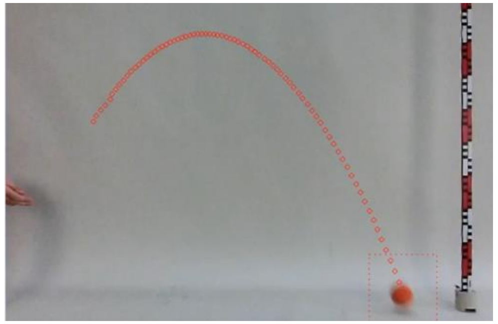
$$\vec{B} = \begin{pmatrix} \dfrac{y}{x^2 + y^2} \\ \dfrac{-x}{x^2 + y^2} \end{pmatrix}$$

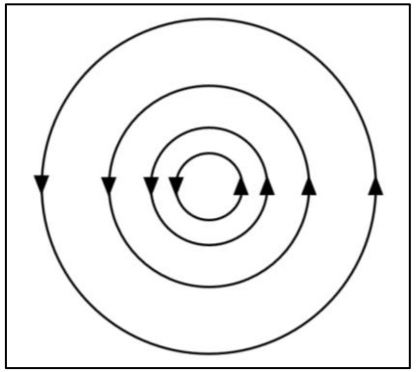




Types of MERs in Physics Education

$$\vec{r} = \begin{pmatrix} v_x t + x_0 \\ -\dfrac{1}{2} g t^2 + v_y t + y_0 \end{pmatrix}$$





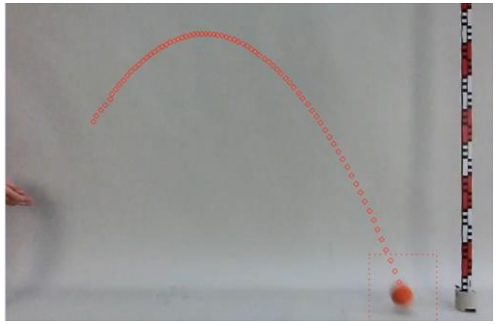
The magnetic field runs circularly around the current-carrying conductor and the magnitude decays outward.

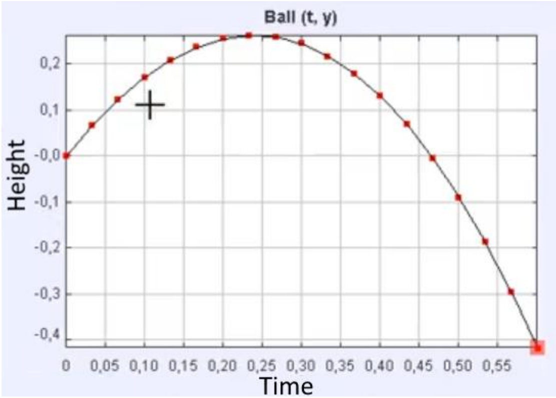
Actional-operational

Visual-graphical

Verbal-textual

Symbolic-mathematical





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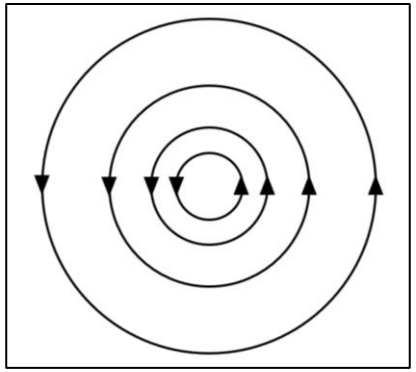
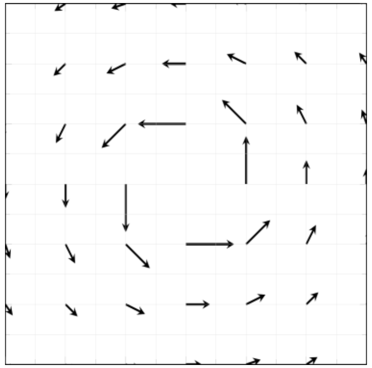
$$\vec{r} = \begin{pmatrix} v_x t + x_0 \\ -\frac{1}{2} g t^2 + v_y t + y_0 \end{pmatrix}$$





The magnetic field runs circularly around the current-carrying conductor and the magnitude decays outward.

$$\vec{B} = \begin{pmatrix} \frac{y}{x^2 + y^2} \\ \frac{-x}{x^2 + y^2} \end{pmatrix}$$

Wu, Puntambekar, J Sci Educ Technol (2012) 21:754–767

Types of MERs in our studies

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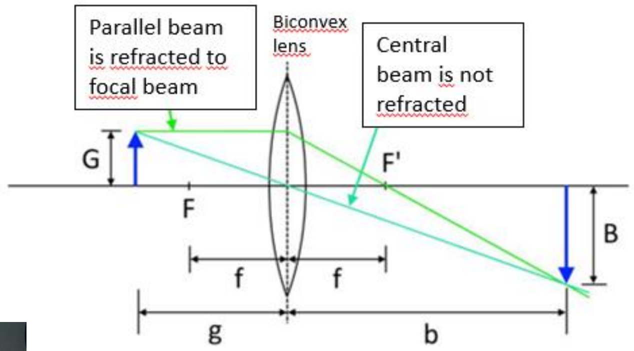
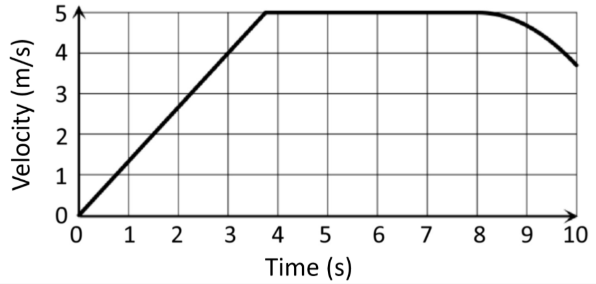
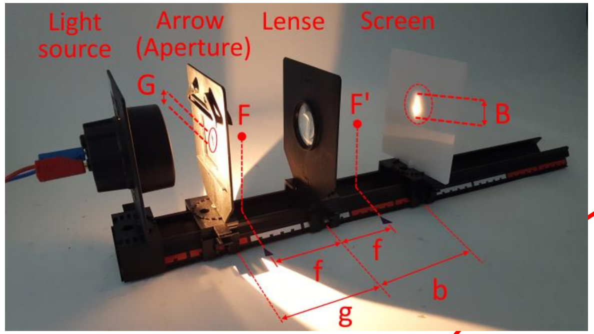
Visual-graphical





Actional-operational



Verbal-textual

The parallel beam runs from the tip of the object parallel to the optical axis to the center of the lens

Representation

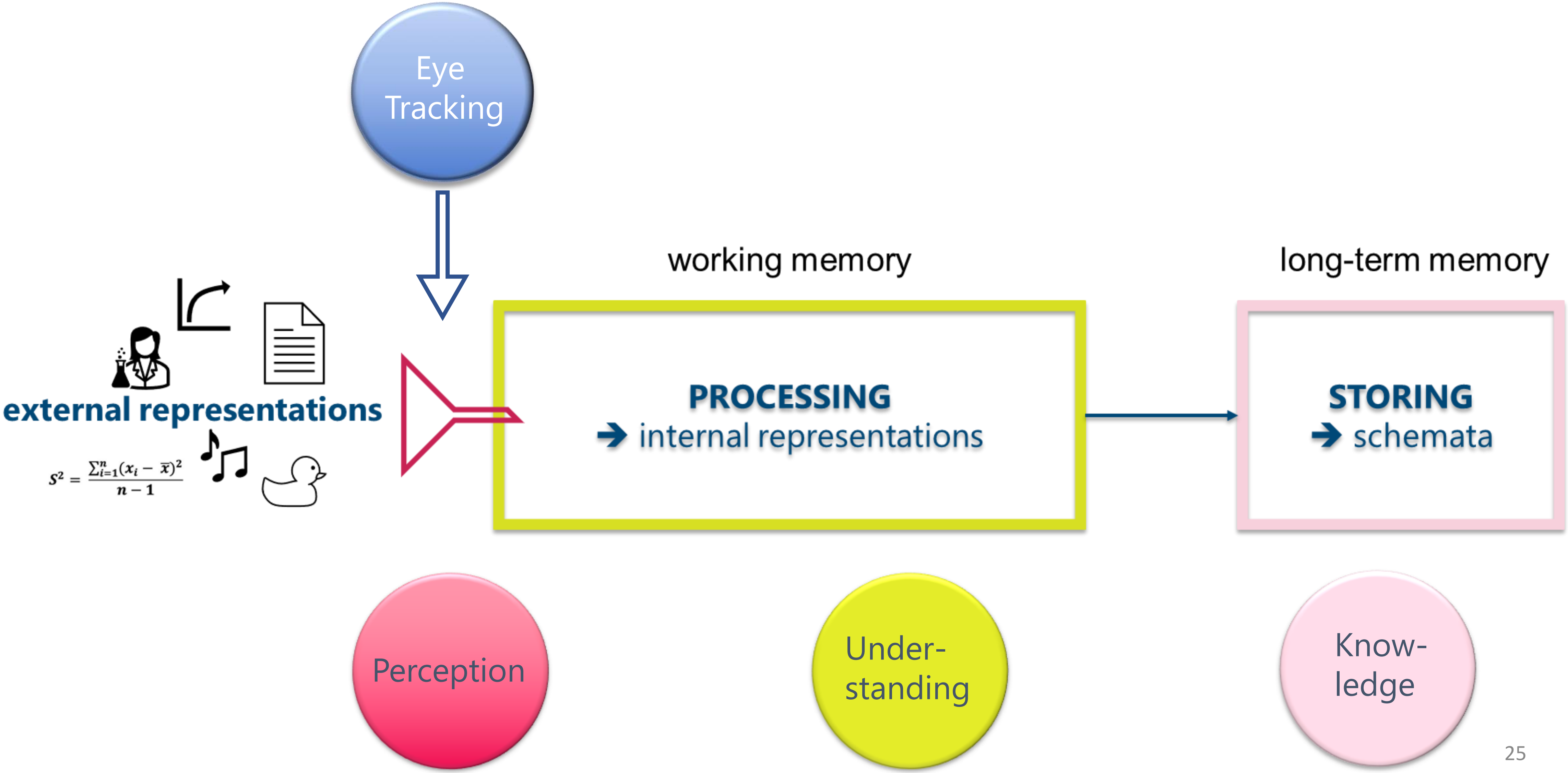
analog

symbolic

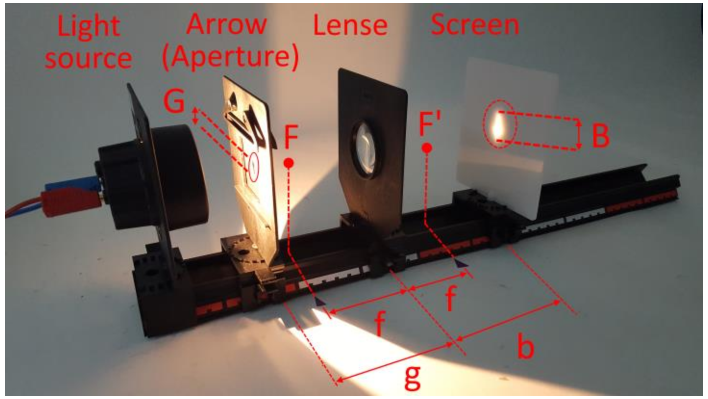
Science phenomenon

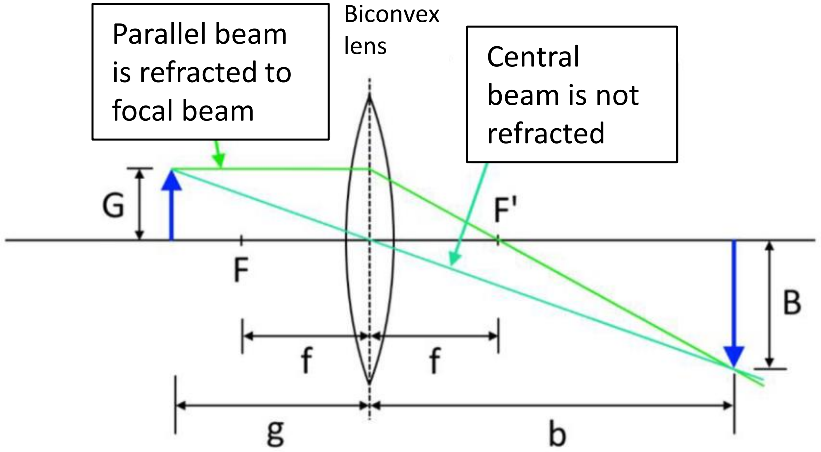
Conceptual knowledge

Eye Tracking: Monitoring Perception



Learning with experiments (actional-operational, visual-graphical, and textual-verbal representations)



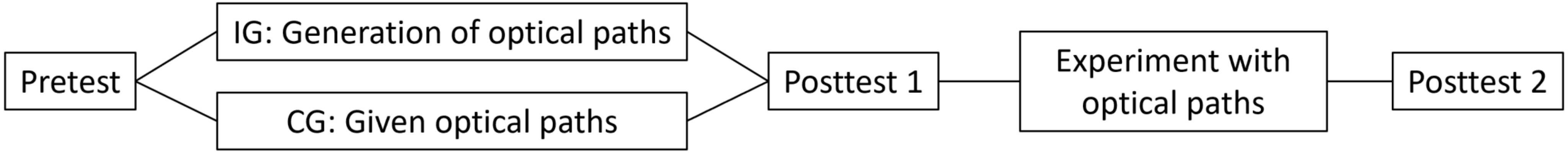


G = Object height
B = Image height
g = object width

b = Image width
f = Focal length

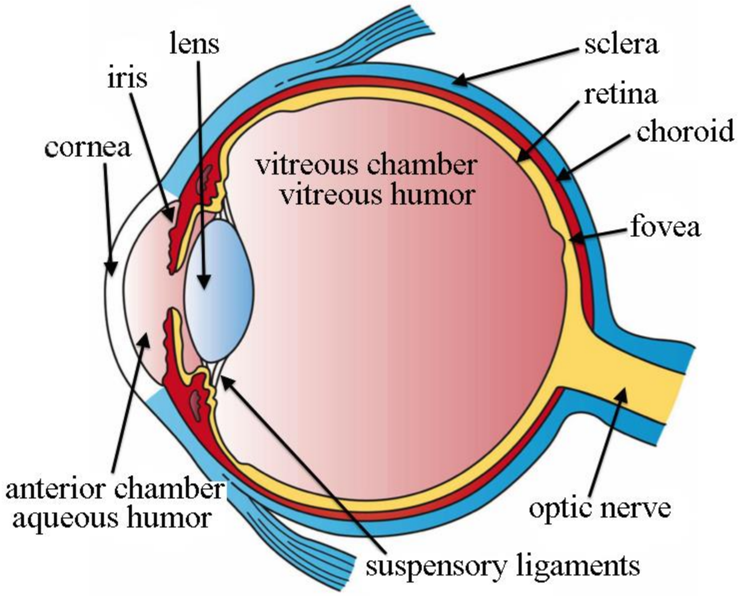
The parallel beam runs from the tip of the object parallel to the optical axis to the center of the lens

Study design



<u>Participants:</u>

- 42 Health science students (IG: N=18, CG: N=24)
- Study during a first semester lab course addressing the concepts of a human eye



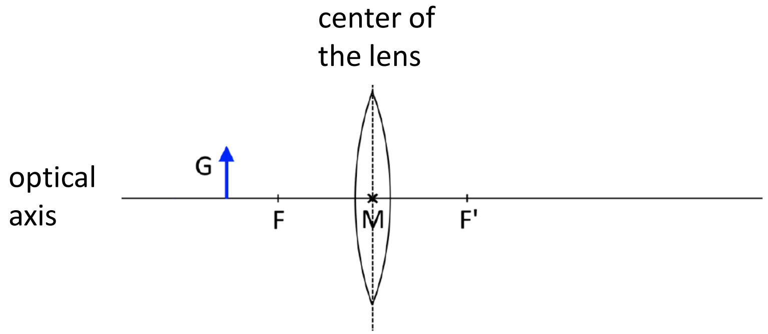
Küchemann, Ruf, Becker, Mukhametov, Klein, Ludwig, Kuhn, (2021), in preparation

Generation and Experimentation

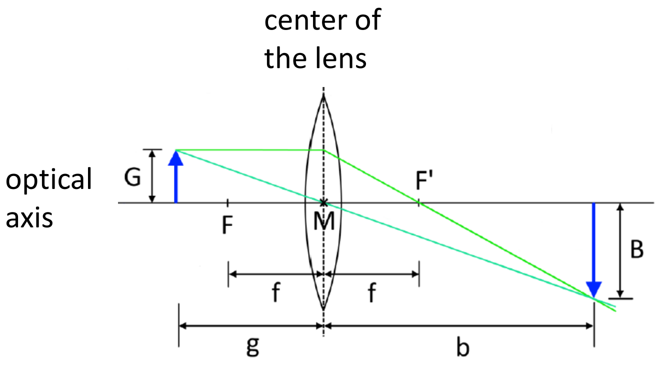
Generation phase:

- 3 Cases in which Optical paths needed to be generated

IG: Generation of optical paths

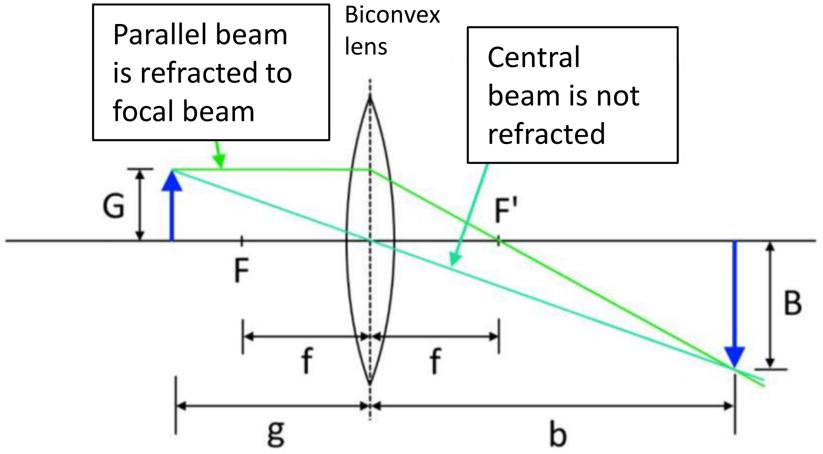


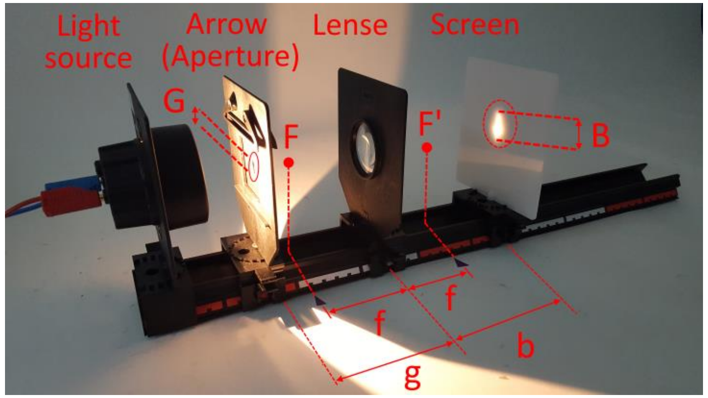
CG: Given optical paths



Experimentation phase:

- 4 Experimental tasks





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Küchemann, Becker, Ruf, Mukhametov, Klein, Ludwig, Kuhn, (2021), in preparation

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Mobile Eye-Tracking during generation of representations and experiments

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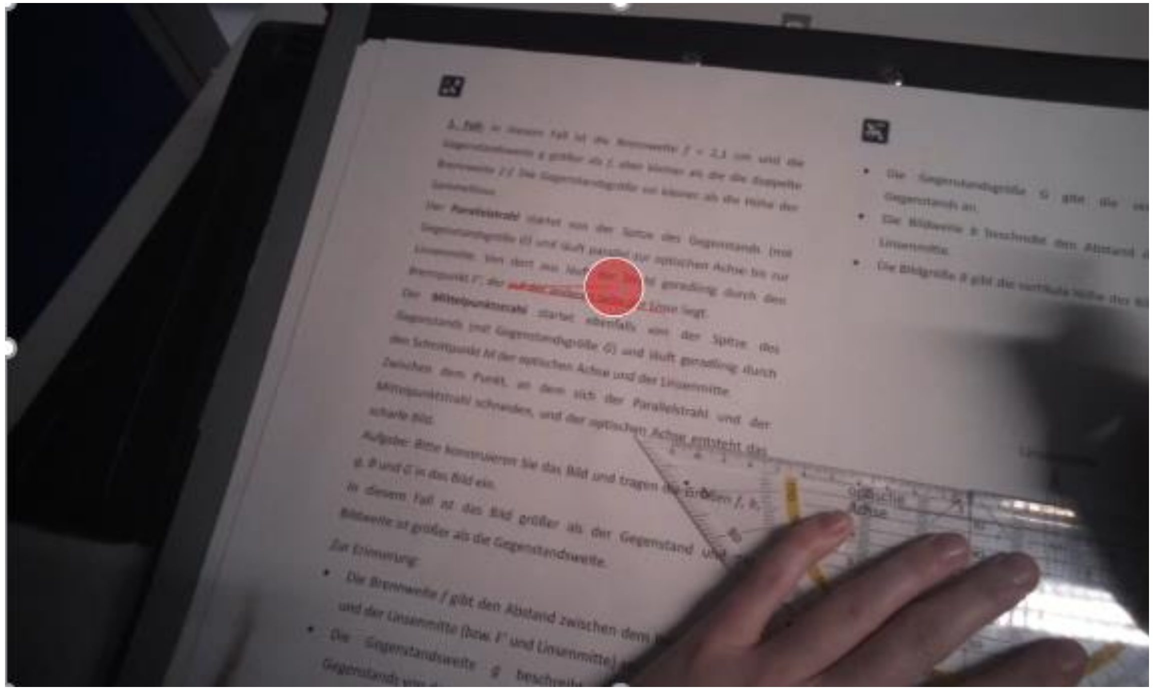
Pretest → IG: Generation of optical paths / CG: Given optical paths → Posttest 1 → Experiment with optical paths → Posttest 2

Video 3

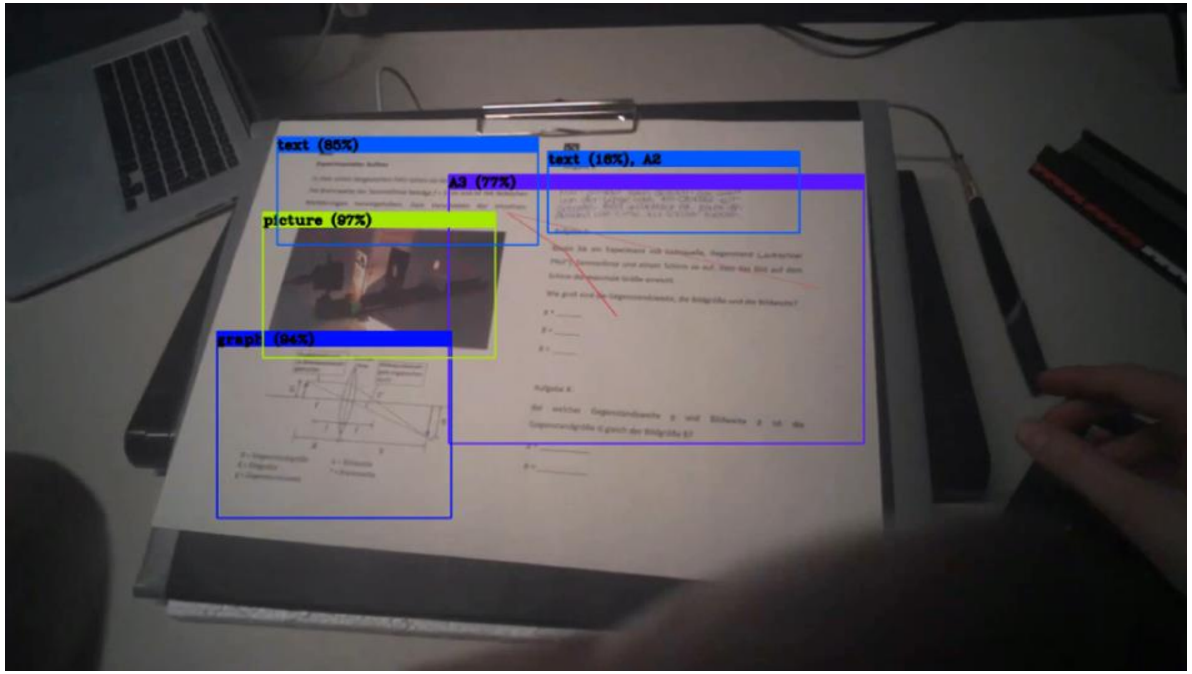


Niharika Kumari, Stefan Küchemann, Verena Ruf, Sergey Mukhametov, Albrecht Schmidt, and Jochen Kuhn (2021), under review

Mobile Eye-Tracking during generation of representations and experiments

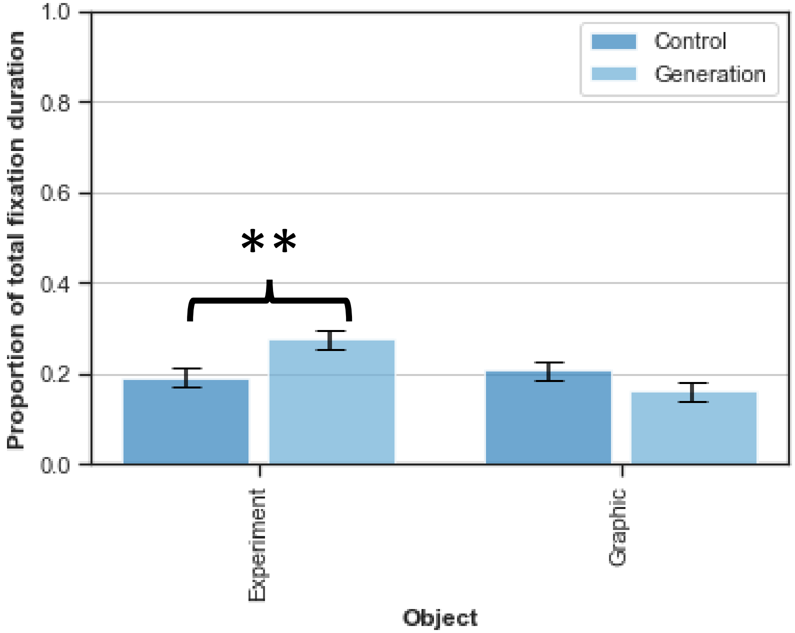
Pretest → IG: Generation of optical paths / CG: Given optical paths → Posttest 1 → **Experiment with optical paths** → Posttest 2

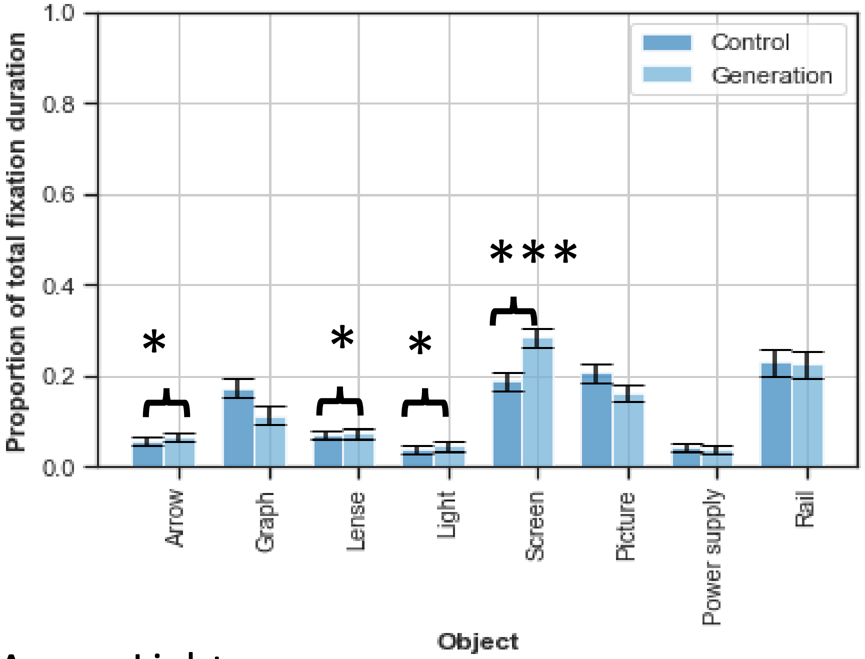
Video 5

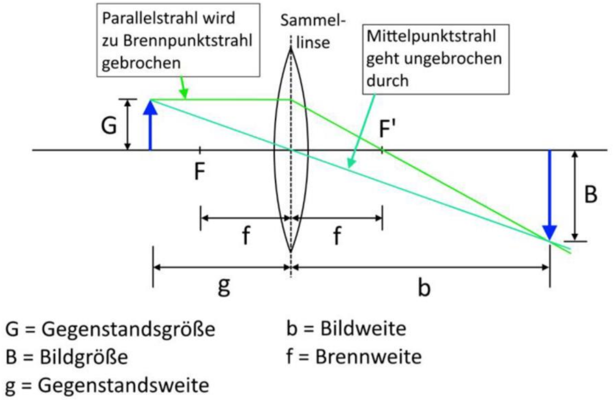


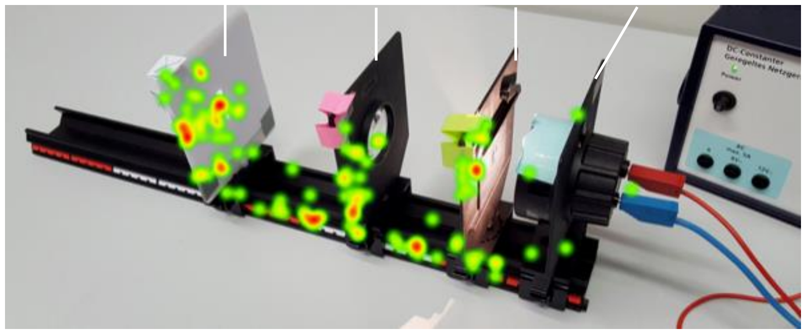
Niharika Kumari, Stefan Küchemann, Verena Ruf, Sergey Mukhametov, Albrecht Schmidt, and Jochen Kuhn (2021), under review

Interaction with the experiment after the generation process



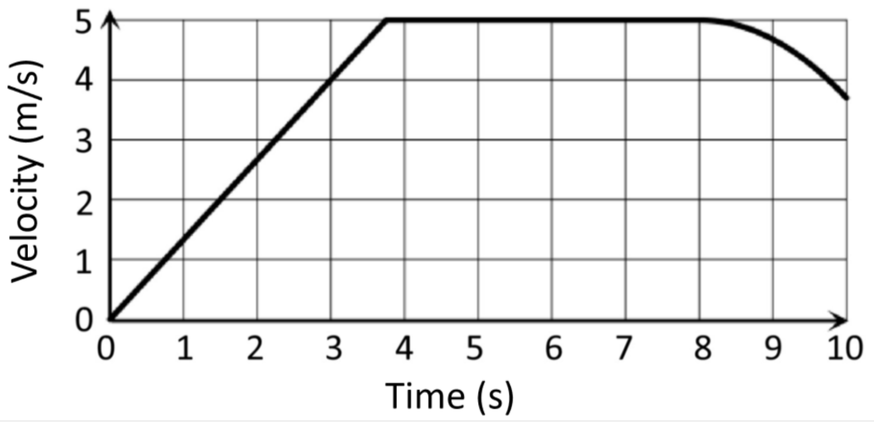






Küchemann, Becker, Ruf, Mukhametov, Klein, Ludwig, Kuhn, (2021), in preparation

Understanding of Graphs



What we know from eye tracking…

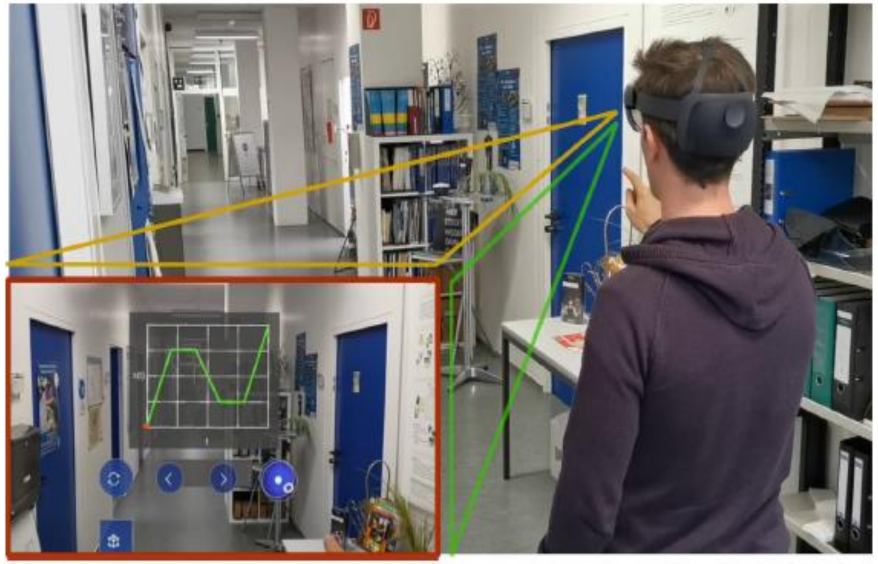
1. Students who determine the slope of a graph correctly focus significantly longer on areas along the graph and on relevant axis intervals and perform more gaze transitions between these areas (Klein et al., 2019; Küchemann et al., 2020).

2. Students' gaze data while solving a graph problem is predictive for the correctness (a support vector machine algorithm provides the best prediction; Küchemann et al., 2020)

Klein, P., Küchemann, S., Brückner, S., Zlatkin-Troitschanskaia, O., & Kuhn, J. (2019). Student understanding of graph slope and area under a curve: A replication study comparing first-year physics and economics students. *Physical Review Physics Education Research*, *15*(2), 020116.

Küchemann, S., Klein, P., Becker, S., Kumari, N., & Kuhn, J. (2020). Classification of Students' Conceptual Understanding in STEM Education using Their Visual Attention Distributions: A Comparison of Three Machine-Learning Approaches. In *CSEDU (1)* (pp. 36-46).

Eye tracking in an embodied AR environment - Walk the graph

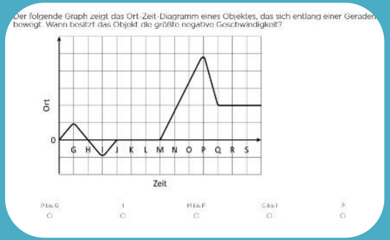


Dzsotjan, D., Ishimaru, S., Ludwig-Petsch, K., Küchemann, S., Mukhametov, S., Kuhn, J., (2021), The Predictive Power of Eye-Tracking Data in an Interactive AR Learning Environment, *eyewear 2021*, accepted

Study design

N=37

Pretest



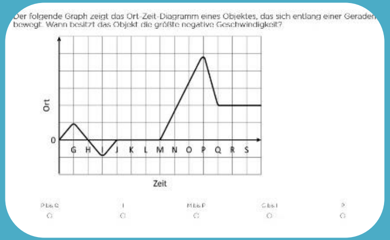
20 min.

Intervention

Walk the graph with the Hololens

5 min.

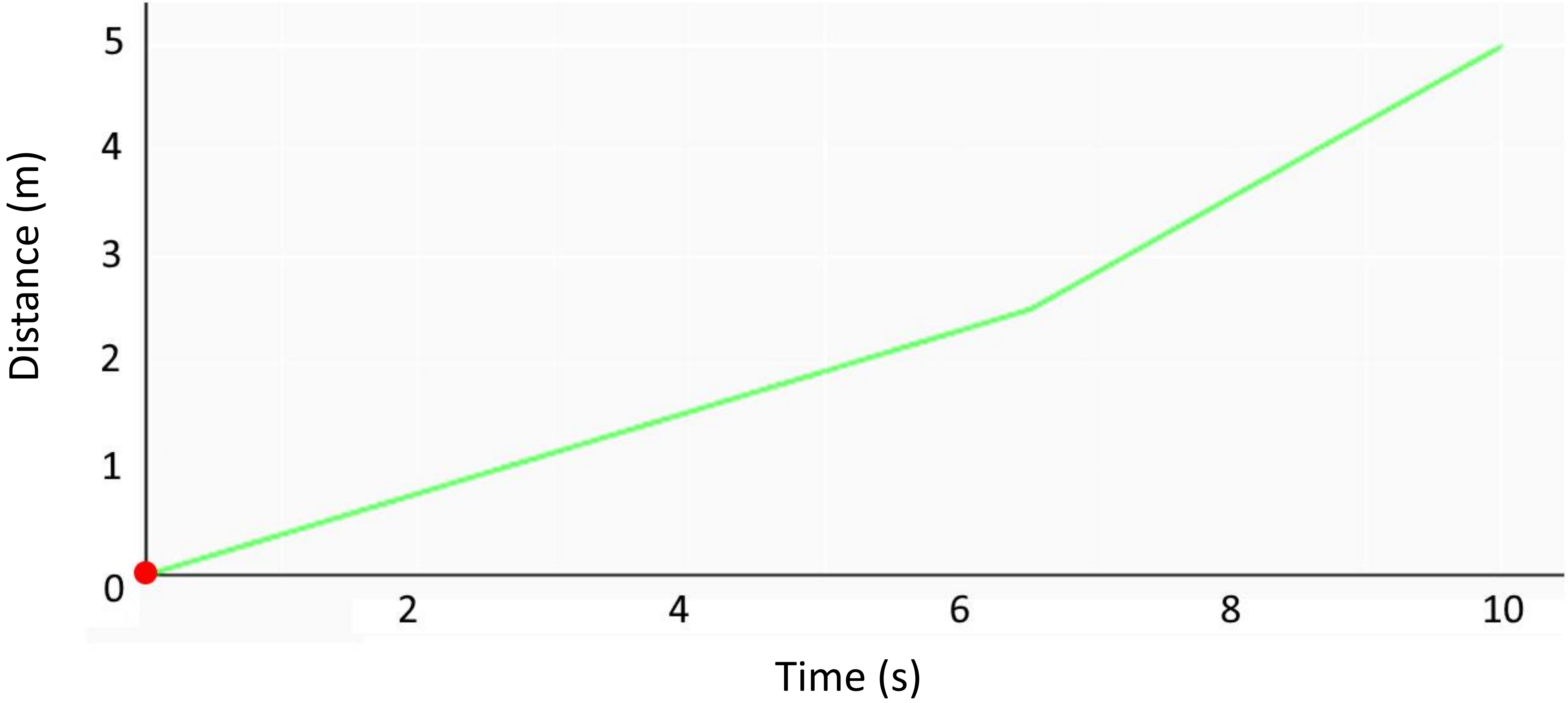
Posttest



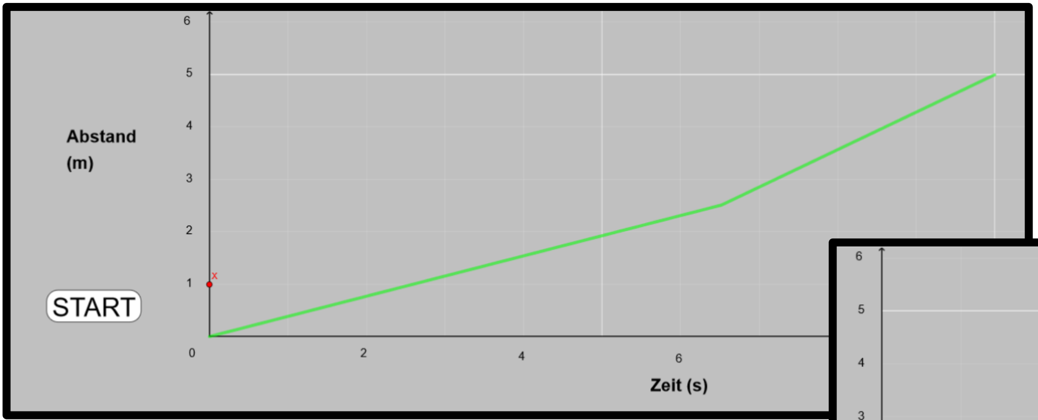
20 min.

Please follow the trend of the graph as closely as possible by walking back or forth.

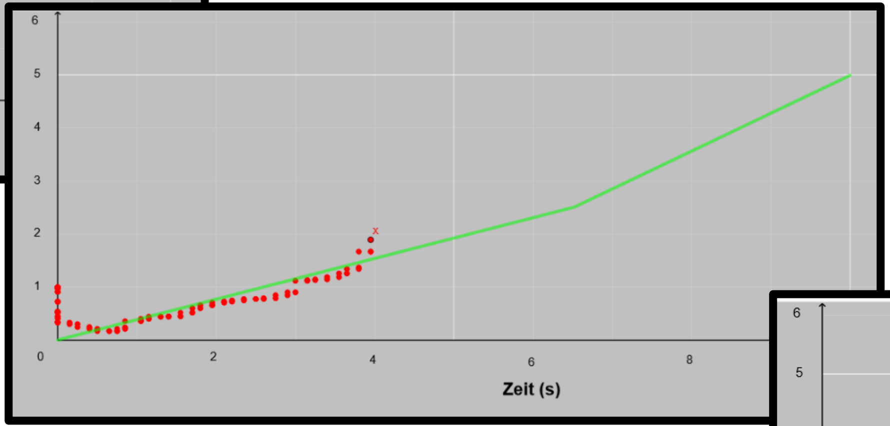
(The red dot indicates your position.)


Distance (m)
0
1
2
3
4
5
2
4
6
8
10
Time (s)

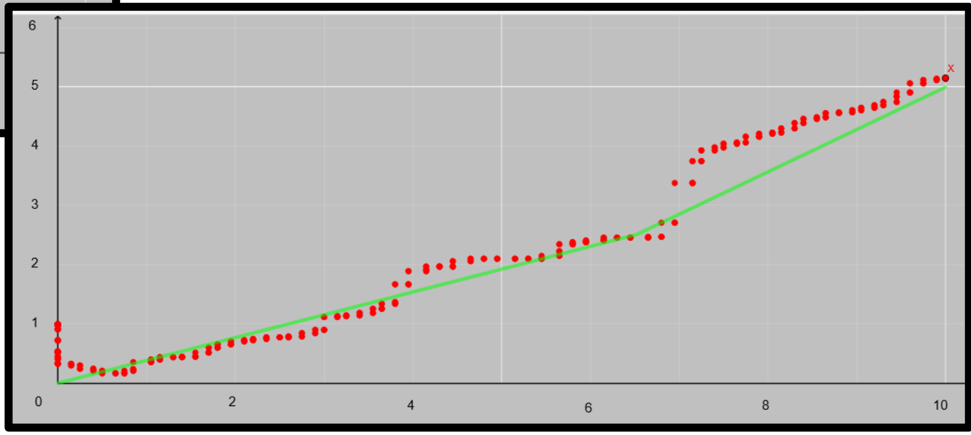
3 Phases for each walk



Planning (ca. 5-10s)

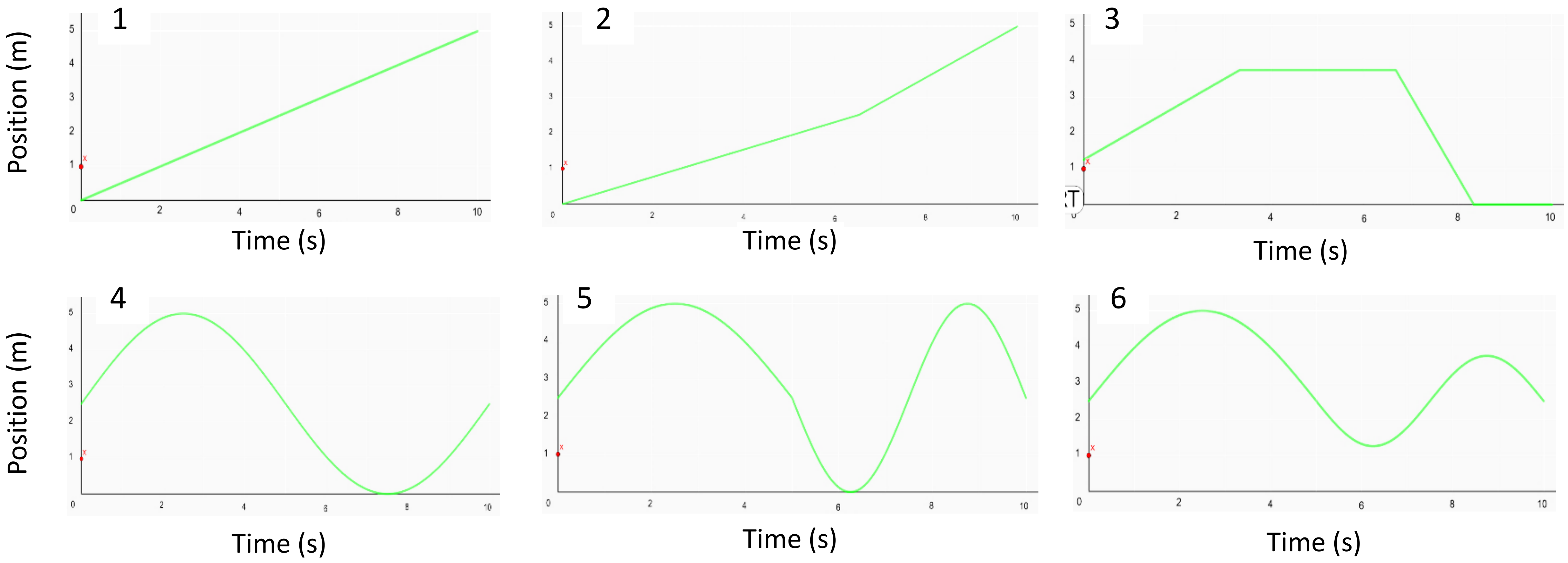


Walk (ca. 10s)

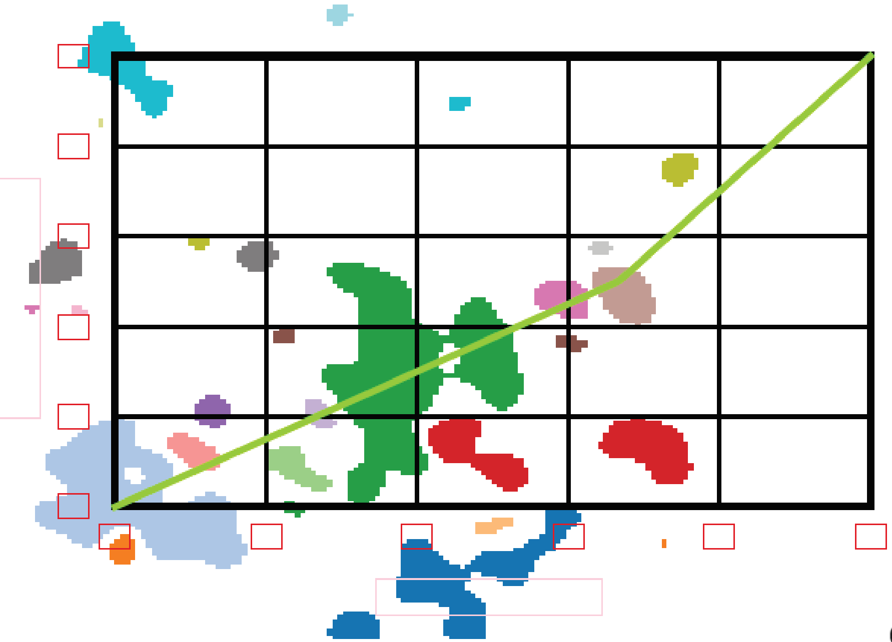


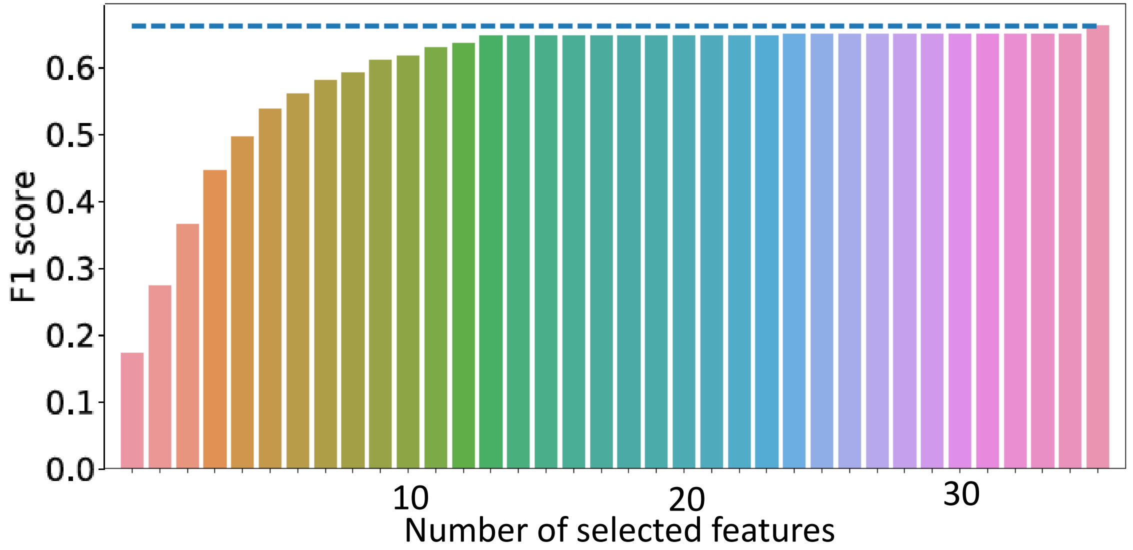
Assessing/Reflecting (ca. 5s)

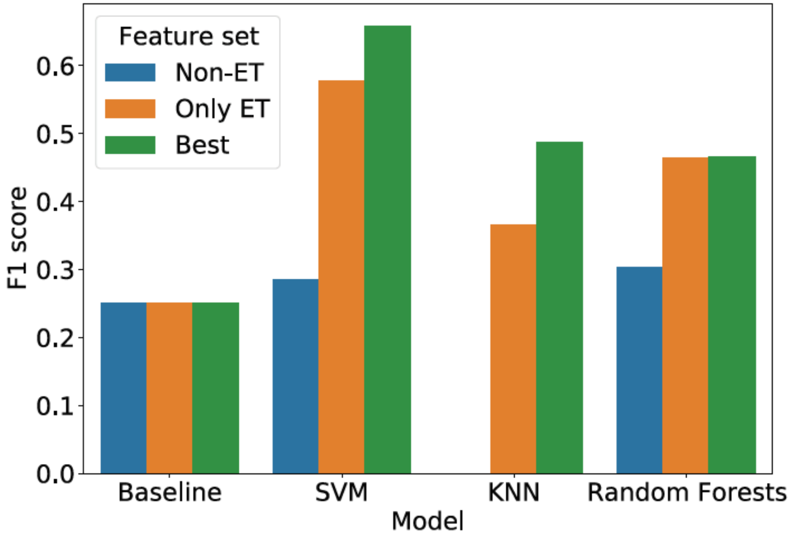
Intervention: Follow the trajectory of 6 different graphs twice



Intervention: Follow the trajectory of 6 different graphs







$$F_1 = \frac{tp}{tp + \frac{1}{2}(fp + fn)}$$

Summary and outlook

Summary and Outlook

- **Learning with „digital Swiss Army Knives“ and AR in inquiry-based learning scenarios:**
  - First research results show positive learning effects compared with „traditional“ settings
  - Depending on learning tasks and presentation format
  - No dealing with abstractness or systematic variation have been studied until now
- **Eye Tracking:**
  - In general: Indicator of preceptual processes
  - For MERs:
    - Relation to cognitive processes
    - Relevance of MERs for the learning process
    - May reveal students strategy to solve a task
    - Gaze behavior may mediate learning success
- **Machine Learning:**
  - Extraction of feature relevance – identification of relevance of eye tracking metrics
  - Very relevant for learning analytics
  - Prediction of learning gain – option to support learning process or immediate feedback

physics education
KUHN Group

Acknowledgement

TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

Physics Education Research Group

Physics Department

Financial Support

Bundesministerium
für Bildung
und Forschung

DFG

Collaborations

UNIVERSITÄT
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VERSITÄT

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IMMERSIVE
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LEARNING
LAB

Contact: s.kuechemann@physik.uni-kl.de