Pädagogische Hochschule Freiburg
Université des Sciences de l'Education · University of Education

Making computer-based learning work for STEM education

Digitalization in the mathematics classroom:
What works for whom—and why?

Frank Reinhold

University of Education Freiburg
Institute for Mathematics Education (IMBF)

Latsis Symposium 2021 STEM: Boosting hidden potentials
2021 September 06–08
Zurich

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Outline

- What effects can be expected from digitalization in STEM education?
- Can different learning prerequisites lead to different effects?
- What can explain differences in learning gains—besides prior knowledge?
- Does log-file data yield insights into students learning processes?
- What could we seek to understand better?

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What effects can be expected from digitalization in STEM education?

Educational technology in secondary STEM education

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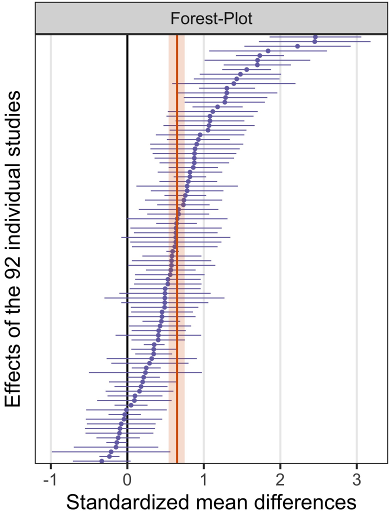
A meta-analytical approach

Positive effect on performance, $k = 92$, $g = 0.65$

- Blended learning formats particularly effective
- Adaptive formats with feedback most effective
- In-service training for teachers beneficial

In addition, positive effect on attitudes towards the subject, $k = 16$, $g = 0.45$

(Hillmayr, Ziernwald, Reinhold, Hofer & Reiss, 2020, *Computers & Education*)



Project funding

KMK KULTUSMINISTER KONFERENZ

STIFTUNG MERCATOR

Can different learning prerequisites lead to different effects?

A very typical erroneous answer in grade 6

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Aufgabe 17 Tom möchte wissen, welcher der beiden Brüche $\frac{8}{9}$ und $\frac{7}{6}$ größer ist.

a) Welcher Bruch ist größer? Kreuze an.

☒ $\frac{8}{9}$ ist größer.	☐ $\frac{7}{6}$ ist größer.	☐ Beide Brüche sind gleich groß.

b) Schreibe eine Erklärung auf.

Weil 8 und 9 größer sind als 7 und 6.

Developing evidence-based digital learning environments

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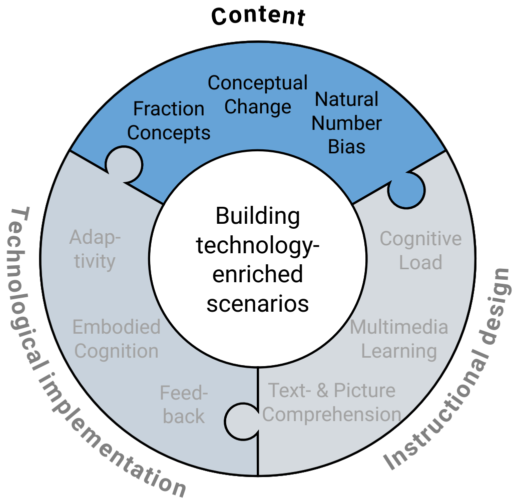


Content

- Fractions represent a challenging mathematical content to learn.

  (Behr et al., 1983; Lortie-Forgues et al., 2015; Winter, 1999)

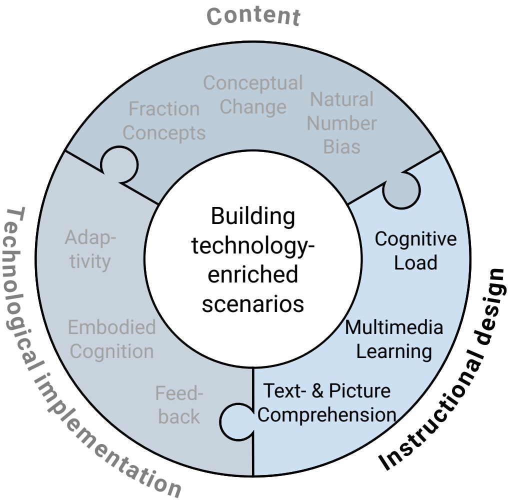
- Sticking to concepts of natural numbers is a source of typical errors.

  (Prediger, 2008; Vamvakoussi & Vosniadou, 2004)

- Tangible actions and transitions between representations meaningful.

  (Bruner, 1960/1970; see also Alibali & Nathan, 2012)

Developing evidence-based digital learning environments



Instructional design

- Processing capacity of working memory is limited.

  (Baddeley, 1992; van Merriënboer & Sweller, 2005)

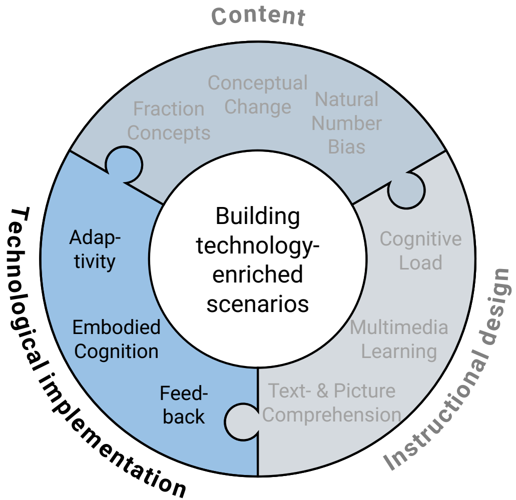
- Low extraneous cognitive load can improve learning processes.

  (Paas & Sweller, 2014; Sweller et al., 1998)

- Words and pictures can be processed separately.

  (Mayer, 2014; Schnotz & Bannert, 2003)

Developing evidence-based digital learning environments



Technological implementation

- Adaptive task difficulty allows for individualized support.

  (Moreno et al., 2006; Steenbergen-Hu & Cooper, 2013)

- Individual feedback can provide additional support.

  (Hattie & Timperley, 2007; Hillmayr et al., 2020; Moreno, 2004)

- Congruent interactions can support learning processes.

  (Clark, 1999; Tran et al., 2017; Wilson, 2002)

Potential of digital tools besides ITS approaches

bit.ly/ALICE-page23

Project funding

Heinz Nixdorf Stiftung

A cluster randomized controlled trial

Sample

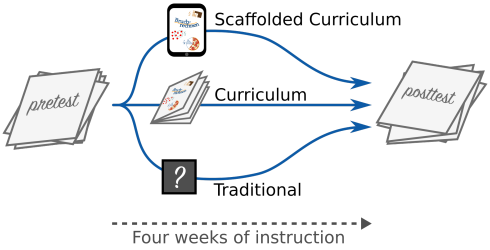
$\mathrm{N} = 1,005$ grade six students

- $n = 745$ $(k = 29)$ at „Gymnasium“
- $n = 260$ $(k = 16)$ at „Hauptschule“

Instruments

- Pretest on prior experience with fractions: 10 Items, $\omega = 0.83$.
- Posttest on fraction comprehension
  Conceptual: 20 Items, $\omega = 0.87$
  Procedural: 18 Items, $\omega = 0.88$

Procedure



Analysis

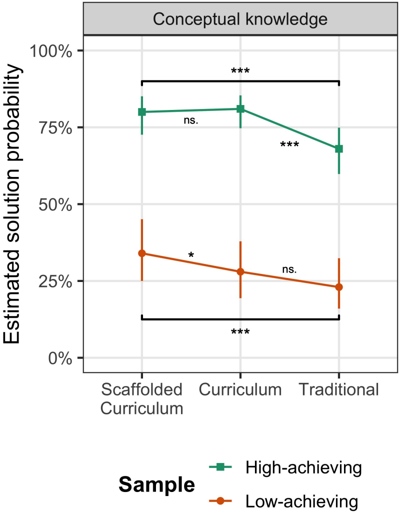
Generalized linear mixed models (GLMM) for binary outcomes and multilevel analysis.

What works—and for whom?

Conceptual knowledge

- Subject matter didactic preparation sufficient for high-achieving learners
- Interactive and adaptive digital support necessary for low-achieving learners

(Reinhold, Hoch, Werner, Richter-Gebert & Reiss, 2020, *Learning and Instruction*)



What works—and for whom?

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Procedural knowledge

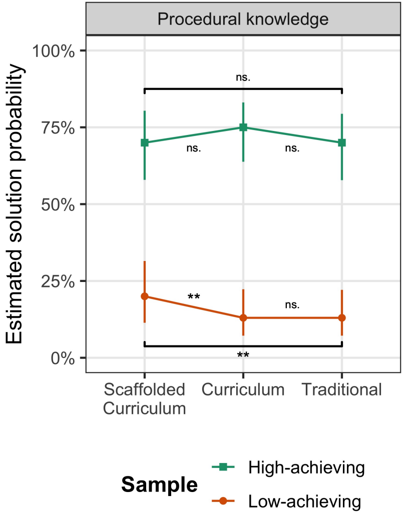
- No significant differences for high-achieving students.
- Digital support effective for low-achieving students

(Reinhold, Hoch, Werner, Richter-Gebert & Reiss, 2020, *Learning and Instruction*)

Sustained effects

- Effects for low-achieving learners remained eight weeks after intervention

(Reinhold, Hofer, Hoch, Werner, Richter-Gebert & Reiss, 2020, *PLOS ONE*)



What can explain differences in learning gains—besides prior knowledge?

Broadening the view beyond RCTs

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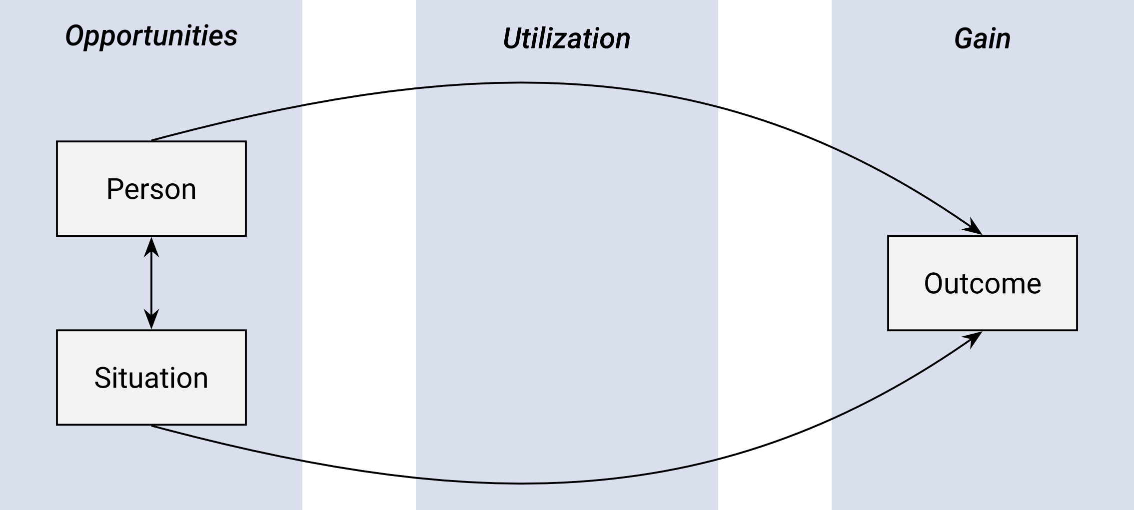
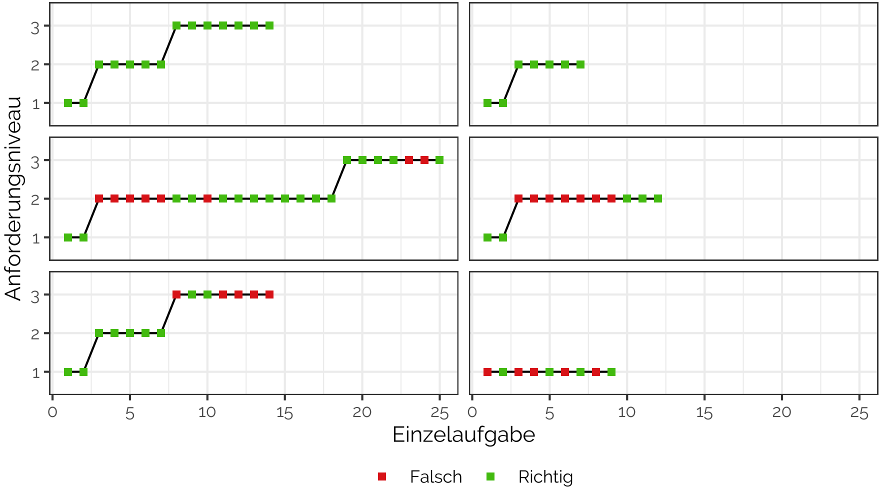


Individual utilization of adaptive task difficulty



(Hoch, 2021, S. 191)

Broadening the view beyond RCTs

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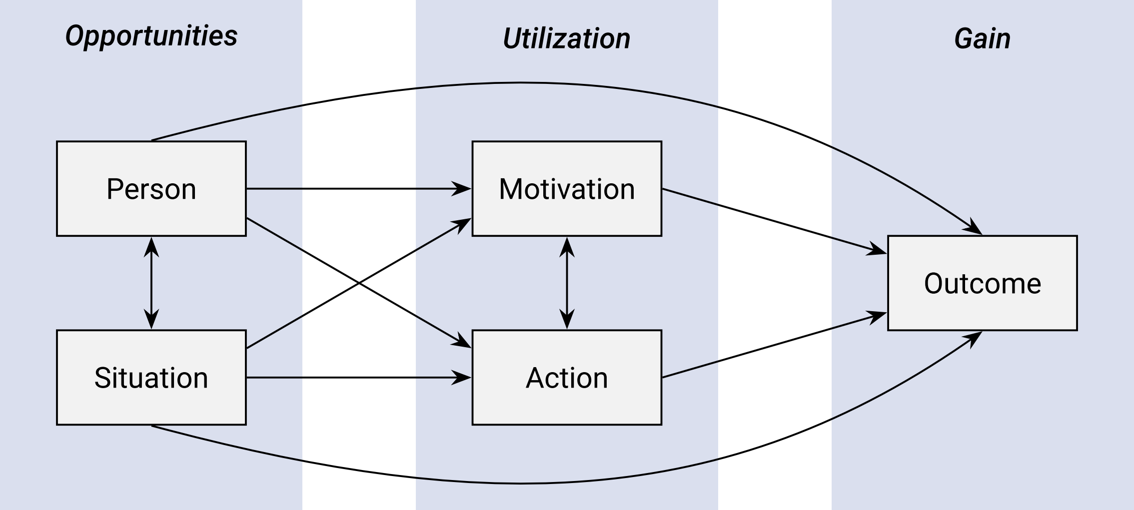
Utilization-of-Learning-Opportunities Models

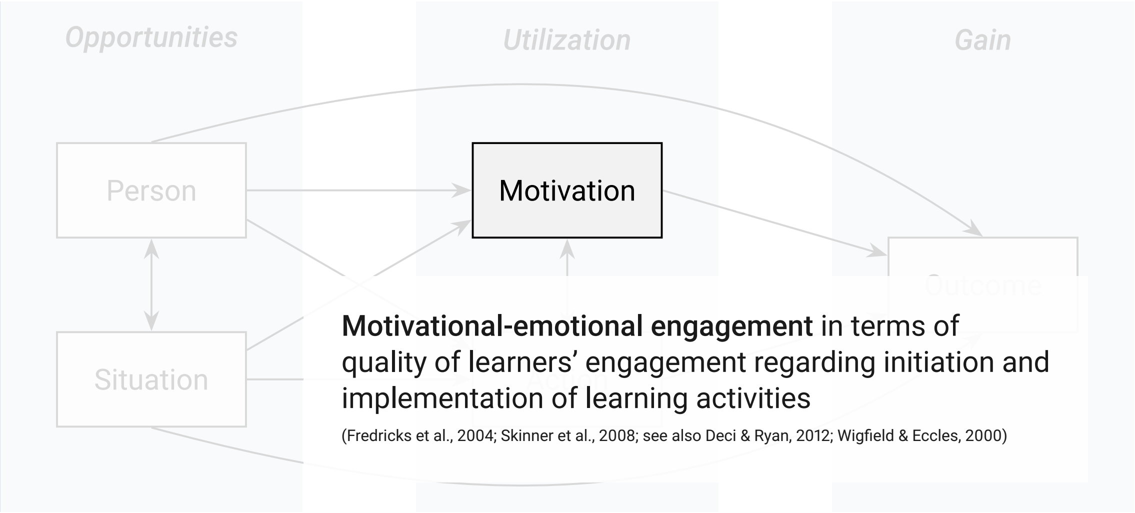
- Technology-enriched classroom settings as learning opportunities of mathematical competence
- Specific utilization of learning opportunities (as „Motivated Action“) moderates instructional success

  (Helmke, 2010; Seidel, 2014; Heckhausen & Heckhausen, 2018)
- Promising mediators for the positive effect of technology-enriched STEM scenarios

The role of „motivated action“ in learning with digital tools



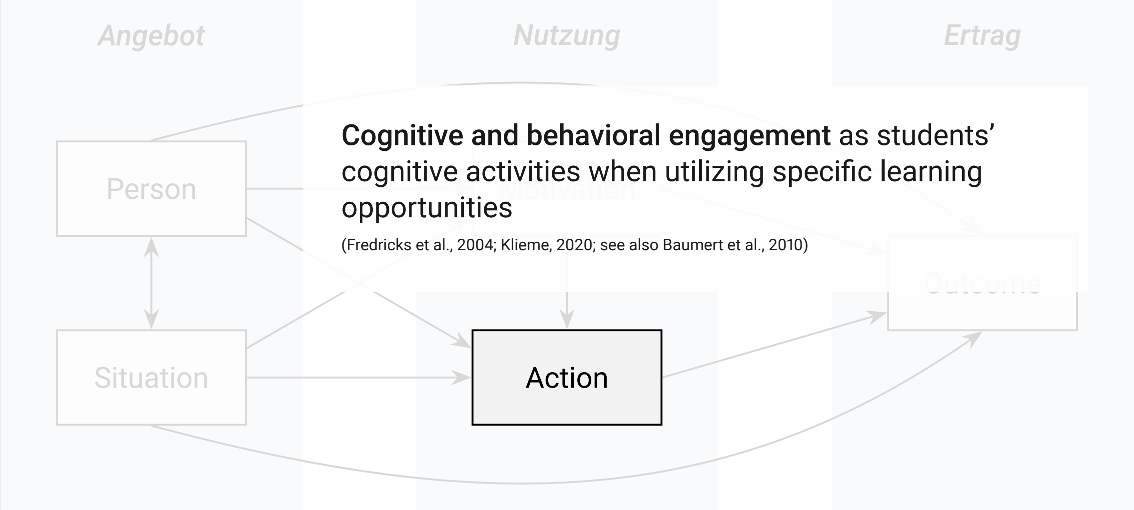
The role of „motivated action“ in learning with digital tools



Motivational-emotional engagement in terms of quality of learners' engagement regarding initiation and implementation of learning activities

(Fredricks et al., 2004; Skinner et al., 2008; see also Deci & Ryan, 2012; Wigfield & Eccles, 2000)

The role of „motivated action“ in learning with digital tools



Cognitive and behavioral engagement as students’ cognitive activities when utilizing specific learning opportunities

(Fredricks et al., 2004; Klieme, 2020; see also Baumert et al., 2010)

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Does log-file data yield insights into students learning processes?

Cognitively activating—but actually actively involved?

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Process data from electronic textbooks indicate students' classroom engagement

Frank Reinhold*, Anselm Strohmaier, Stefan Hoch, Kristina Reiss, Ricardo Böheim, Tina Seidel

Technical University of Munich, TUM School of Education, Germany

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Fractions
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Cluster analysis

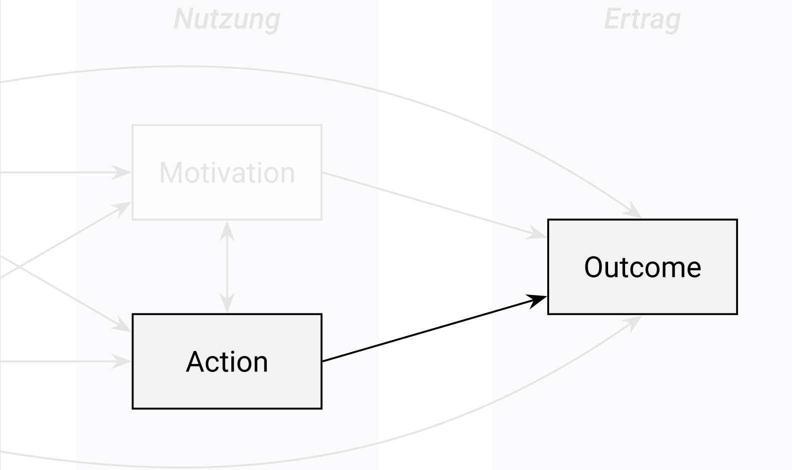
ABSTRACT

Electronic learning environments used in mathematics lessons offer new ways to assess and analyze students' classroom engagement during authentic learning settings. In this study, we investigated students' electronic textbook-use as a measure for their individual engagement during mathematics instruction. To this end, we combined quantity measures (i.e., time on task, text length) and quality measures (i.e., on topic, mathematically valid, mathematical language used). Cluster analysis based on process data of 253 six-graders—who worked on three writing-to-learn exercises during fraction instruction—revealed four different clusters that we ordered hierarchically in terms of engagement, revealing gender differences in favor of girls. Analyses showed negligible differences in prior knowledge between the clusters, yet significant achievement differences in a posttest—with higher engaged clusters reaching higher outcomes. Our approach offers a viable way to unobtrusively measure students' classroom engagement utilizing process data from electronic textbooks.

1. Introduction

measures of engagement utilized in the present study can be attributed to the behavioral and cognitive dimension of engagement.

Reinhold, Strohmaier, Hoch, Reiss, Böheim & Seidel (2020) *Learning and Ind. Differences*



Cognitively activating—but actually actively involved?

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Method

- **Design:** pre-post design with students working on iPads for 15 math lessons while collecting log-file data
- **Sample:** $N = 253$ grade six students, among them $n = 110$ girls
- **Analysis:** focus on
  - 3 writing-to-learn activities
  - with stimulus questions
  - following interactive explorations
  - distributed throughout the learning sequence in lessons 1, 7, and 10

Results and Highlights

- Prior knowledge accounted for $42\,\%$ of the variance in the posttest outcome on the student random intercept.
- Clustering on indicators for cognitive and behavioral engagement revealed four *engagement types*.
- Engagement types were *not* related to prior knowledge *but* to the posttest outcome (additional $22\,\%$).

Technology-enriched STEM education: What could we seek to understand better?

Discussion

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Making computer-based learning work for STEM education

- **Widely empirically validated:** Digital tools as a profitable supplement in STEM learning—especially for low-achieving students

  (Pepin et al., 2017; see also Hoch et al., 2018; Reinhold et al., 2019; Reinhold, Hoch, Werner et al., 2020)

- **Still rather open question:** But why exactly? Further classroom research needed—to secure and understand cause-effect relationships

  (Schmidt-Thieme & Weigand, 2015; siehe auch de Jong, 2009; Kucirkova, 2014)

  - What works for whom—and why?
  - Greater consideration of motivational-emotional engagement
  - Focused study of cognitive activities in the use of digital tools
  - Role of teachers in providing instruction in digital learning settings

- **Potential “killer research feature”:** Process and log-file data

  (Goldhammer et al., 2017; Greiff et al., 2015; Henrie et al., 2015; Hoch et al., 2018; Junco & Clem, 2015)

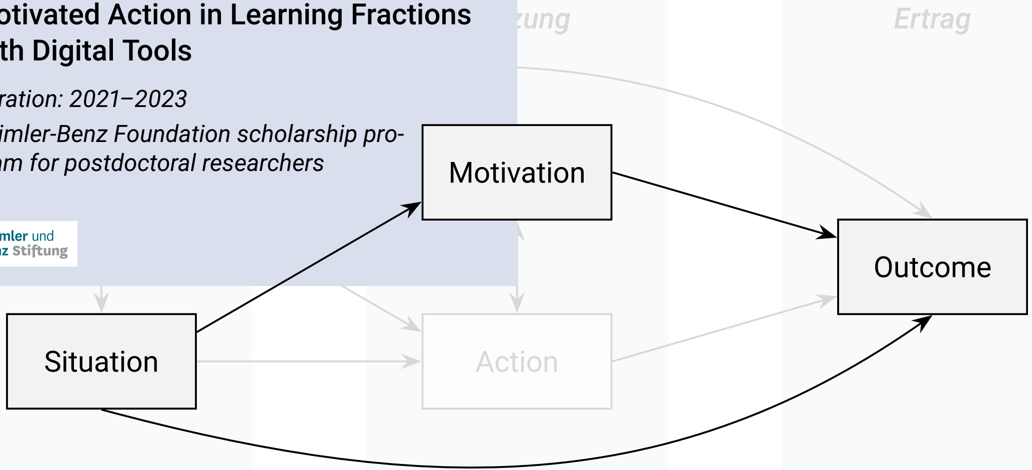
Project *frACTIONs*

Motivated Action in Learning Fractions with Digital Tools

Duration: 2021–2023

Daimler-Benz Foundation scholarship program for postdoctoral researchers

Daimler und Benz Stiftung



Post graduate program *Di.ge.LL*

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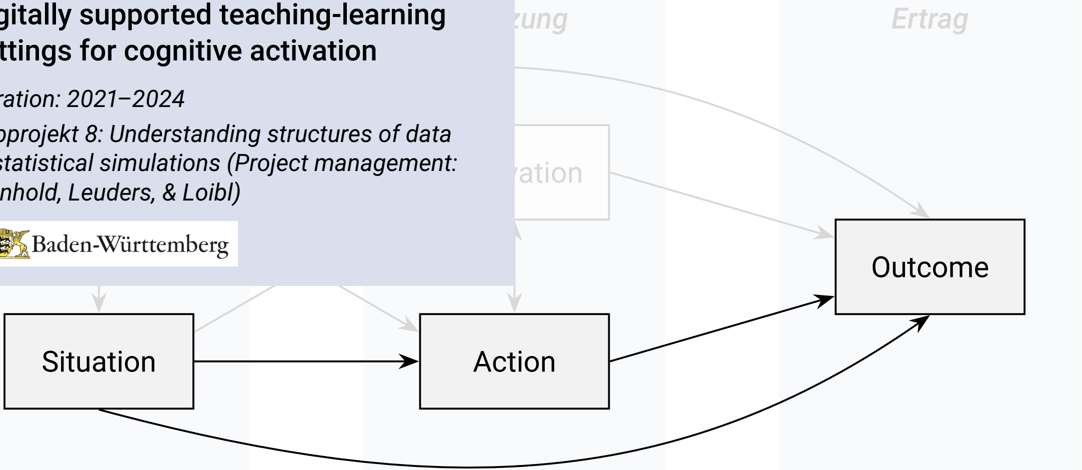
Digitally supported teaching-learning settings for cognitive activation

Duration: 2021–2024

Subprojekt 8: Understanding structures of data in statistical simulations (Project management: Reinhold, Leuders, & Loibl)

Baden-Württemberg



Thank you for your attention.

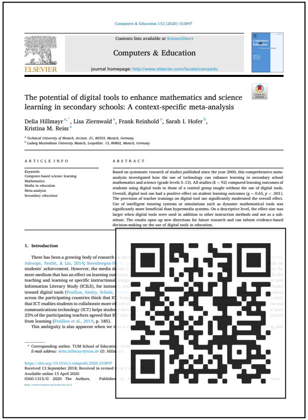
Pädagogische Hochschule Freiburg

Dr. Frank Reinhold

Research and Teaching Associate

University of Education Freiburg
Institute for Mathematics Education

- frank.reinhold@ph-freiburg.de
- https://frankreinhold.education/
- @Reinhold_Edu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The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis

Delia Hillmayr[a,*], Lisa Ziernwald[a], Frank Reinhold[a], Sarah I. Hofer[b], Kristina M. Reiss[a]

Hillmayr, Ziernwald, Reinhold, Hofer & Reiss (2020) *Computers & Education*


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Learning fractions with and without educational technology: What matters for high-achieving and low-achieving students?

Frank Reinhold[a,*], Stefan Hoch[a], Bernhard Werner[b], Jürgen Richter-Gebert[b], Kristina Reiss[a]

Reinhold, Hoch, Werner, Richter-Gebert & Reiss (2020) *Learning and Instruction*