



Content-specific analyses of log data in technology-enriched learning scenarios: Modeling individual cognitive processes while learning box plots

Network Meeting: “Data is confusing, theory is illuminating”

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The CoDiL framework

Learning (math) as individual content-specific processes to generate knowledge

- Acquiring knowledge components in digitally-enriched educational settings
- Learning activities when learning (math) with digital tools
- Digitally-enriched instructional features as opportunities stimulating learning activities
- Linking students' on-task behavior and learning

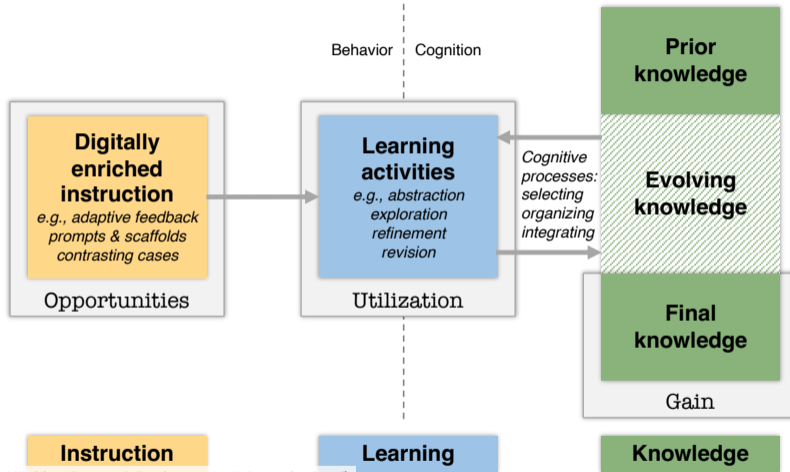
Theoretical framework “setting the stage” for ...

Structured research program with 12 subprojects (3 in math) located in Freiburg

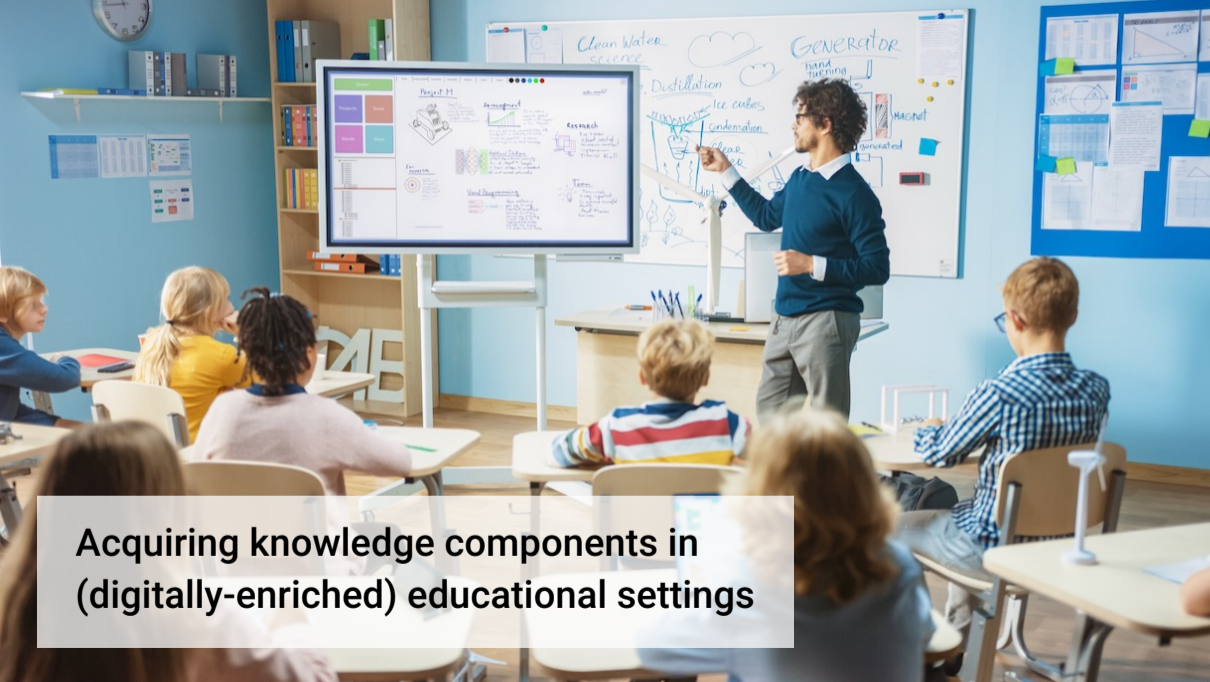


Baden-Württemberg

The CoDiL framework



(Reinhold, Leuders, Loibl, Nückles, Beege, & Boelmann, revision submitted)



**Acquiring knowledge components in
(digitally-enriched) educational settings**

Acquiring knowledge components in educational settings

Learning as an active, constructive, and content-specific cognitive process

Explaining learning should explicate **internal** and **unobservable** learning processes and learning outcomes.

(KLI framework by Koedinger et al., 2012; see also Mayer, 2014; Yeo & Fazio, 2019)

Explicating knowledge components as a first step

Example: Explanatory model of learning how to compare the size of fractions

- **Prior knowledge:** Natural numbers, part-whole, fraction equivalence

(Post & Cramer, 1987)

- **Evolving knowledge:** Isolated comparisons of numerator or denominator

(Gómez & Dartnell, 2019)

- **Final knowledge:** Repertoire of various correct comparison strategies

(Clarke & Roche, 2009)

A man with short brown hair, wearing a blue and white checkered button-down shirt, is leaning over a young girl with long brown hair. The girl is wearing a white and blue striped shirt under denim overalls. They are both looking intently at a tablet computer that the man is holding. They are sitting at a dark grey table in what appears to be a classroom. In the background, other children are seated at desks, and a bulletin board with colorful paper airplanes is visible. A small, patterned pouch and a notebook are on the table next to them.

**Learning activities when
learning with digital tools**


Cognitive models of student knowledge do not guarantee learning success

Explaining learning should integrate structural aspects of learning environments and **actual processes that students undergo** during instruction.

(Utilization-of-learning-opportunities framework by Seidel, 2014; see also Alp Christ et al., 2022; Seidel & Shavelson, 2007; Fredricks et al., 2004)

Examples of learning activities

- **Exploration:** Initial examination for activating prior knowledge and raising questions
(Lachner et al., 2022)
- **Revision:** Fundamental restructuring of naïve concepts to allow understanding
(Duit & Treagust, 2003; Vosniadou, 1994)
- **Self-explanation:** Explaining content to oneself for deepened processing
(Renkl et al., 1998)



Digitally-enriched instructional features as opportunities stimulating learning activities

Opportunities stimulating learning activities

Digitally-enriched instructional features

Instructional events which are subject of **affordances and constraints** that have the potential to **increase generative processing** (and to lower extraneous load).

(Schumacher & Stern, 2023; Sweller, 2020)

Examples of digitally-enriched instructional features

- **Adaptive feedback** may aid exploration or initiate revision.


(Reinhold, Hoch, et al., 2020; Hillmayr et al., 2020)

- **Prompting to reconsider strategies** while solving tasks may stimulate revision.

(Rau et al., 2009; Rittle-Johnson et al., 2017)

- **Prompting to summarize instructional information** may stimulate self-explanation.

(Hofer et al., 2018; Reinhold, Strohmaier, et al., 2020)

A photograph of a diverse group of elementary school students in a classroom. In the foreground, a young girl with curly hair and a plaid shirt is smiling while holding a tablet. Next to her, a boy in a dark blue polo shirt is looking at his tablet. Other students are visible in the background, some using tablets and others looking towards the camera. The classroom has a blue bulletin board and shelves in the background.

**Linking students' on-task behavior
and learning**

Linking students' on-task behavior and learning

Operationalization of cognitive activities via student-tool-interactions

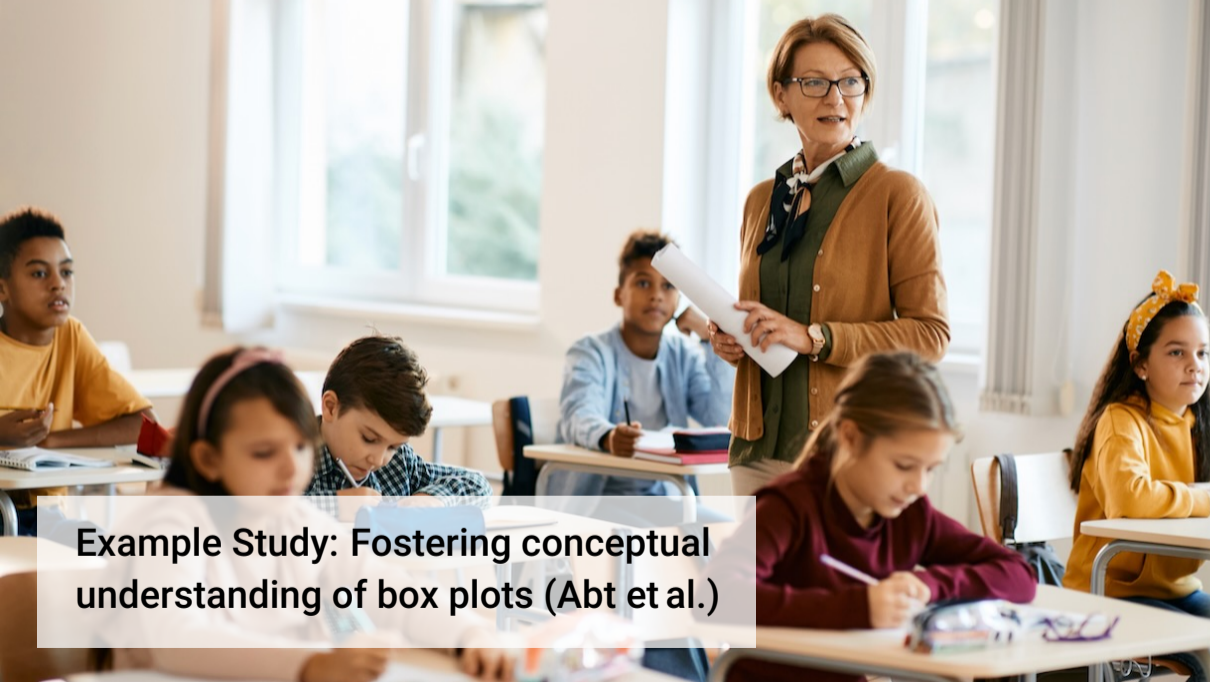
Learning activities link students' **external, behavioral interaction** with the tool and students' **internal, cognitive processes** that lead to knowledge acquisition.

(Goldhammer et al., 2017, 2021; Goldhammer & Zehner, 2017; Greiff et al., 2015; Reinhold, Strohmaier, et al., 2020)

Examples of “process data”

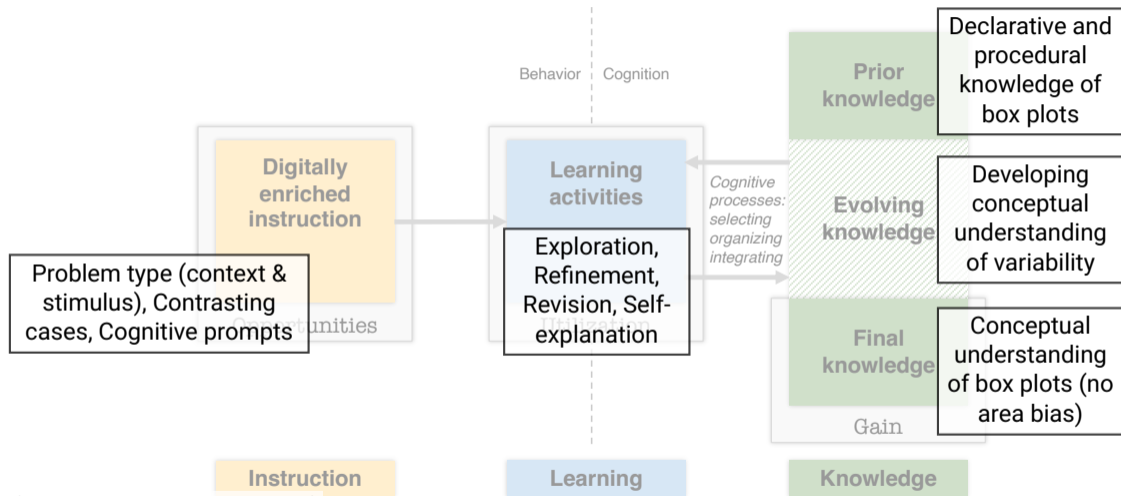
- Student-tool interactions logged unobtrusively by the digital tool itself
- Process indicators obtained from accompanying assessments during learning:
 - Solutions from closed unique cognitive items inside a digital learning path
 - Eye-tracking data
 - Think-aloud protocols accompanying the use of any kind of digital tool
 - Journal writing during self-regulated learning with digital tools

(Moyer-Packenham et al., 2019; Zuo & Lin, 2022; Nückles, 2021; Strohmaier et al., 2020; Nückles et al., 2020; Ericsson & Simon, 1998)



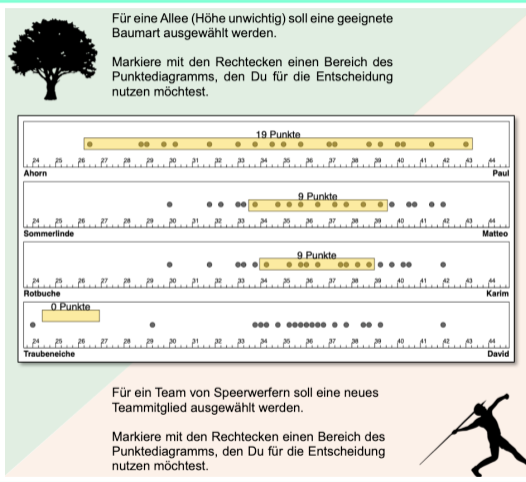
Example Study: Fostering conceptual understanding of box plots (Abt et al.)

Specifying the CoDiL framework for Martin's study



(Abt, Leuders, Loibl, & Reinhold, submitted)

Specifying the CoDiL framework for Martin's study



Problem type (context & stimulus), Contrasting cases, Cognitive prompts

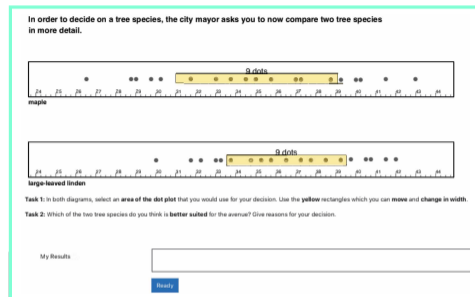
Declarative and procedural knowledge of box plots

Developing conceptual understanding of variability

Conceptual understanding of box plots (no area bias)

(Abt, Leuders, Loibl, & Reinhold, submitted)

Specifying the CoDiL framework for Martin's study



Standards, Contrasting cases, Cognitive prompts

Instruction

(Abt, Leuders, Loibl, & Reinhold, submitted)

Behavior Cognition

Learning activities

Exploration, Refinement, Revision, Self-explanation

Learning

Prior knowledge

Declarative and procedural knowledge of box plots

Evolving knowledge

Developing conceptual understanding of variability

Final knowledge

Conceptual understanding of box plots (no area bias)

Gain

Knowledge

Cognitive processes: selecting organizing integrating

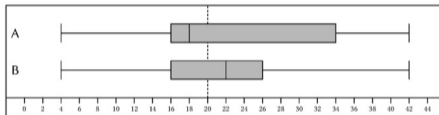
Specifying the CoDiL framework for Martin's study

Digitally
enriched
instruction

Problem type (context & stimulus), Contrasting cases, Cognitive prompts

Instruction

Two schools A and B were attended by equal numbers of children. All children indicated in a survey how long they need to get to school in the morning. Each box plot represents the result for one school.



The number of children with a school commute of more than 20 minutes is higher at one school than at the other.

Decide at which one.

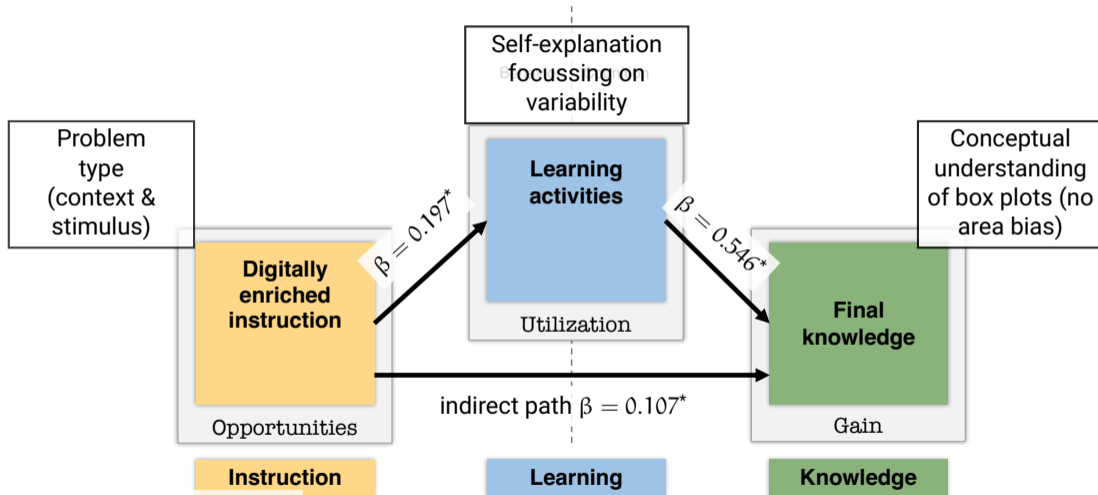
- ☐ school A
- ☐ school B

Declarative and procedural knowledge of box plots

Developing conceptual understanding of variability

Conceptual understanding of box plots (no area bias)

Main result from the SEM (controlling for covariates)



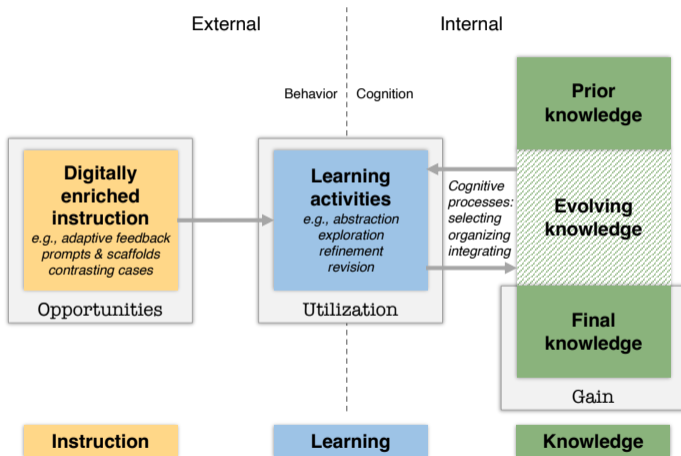
(Abt, Leuders, Loibl, & Reinhold, submitted)

Discussion

Outlook

Research on learning (math) in digitally-enriched scenarios may focus on:

- Cause-and-effect models in digitally-enriched settings
- Explicit theories of “what works **how**”
- Appropriate indicators inside process data
- Explicit mediation analyses in intervention studies



(Reinhold et al., revision submitted)

Thank you for your attention!

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Linking students' on-task behavior and learning

en-GB Programme for International Student Assessment 2012

CLIMATE CONTROL

You have no instructions for your new air conditioner. You need to work out how to use it.

You can change the top, central and bottom controls on the left by using the sliders (\rightarrow). The initial setting for each control is indicated by \blacktriangle .

By clicking APPLY, you will see any changes in the temperature and humidity of the room in the temperature and humidity graphs. The box to the left of each graph shows the current level of temperature or humidity.

Top Control: $-- \quad - \quad \blacktriangle \quad + \quad ++$

Central Control: $-- \quad - \quad \blacktriangle \quad + \quad ++$

Bottom Control: $-- \quad - \quad \blacktriangle \quad + \quad ++$

Temperature: 33

Humidity: 25

APPLY RESET

Question 1: CLIMATE CONTROL CP025Q01

Find whether each control influences temperature and humidity by changing the sliders. You can start again by clicking RESET.

Draw lines in the diagram on the right to show what each control influences.

To draw a line, click on a control and then click on either Temperature or Humidity. You can remove any line by clicking on it.

Top Control → Temperature

Central Control

Bottom Control

Temperature

Humidity

?

→

(Greiff et al., 2015, p. 96)

Fostering conceptual understanding of box plots

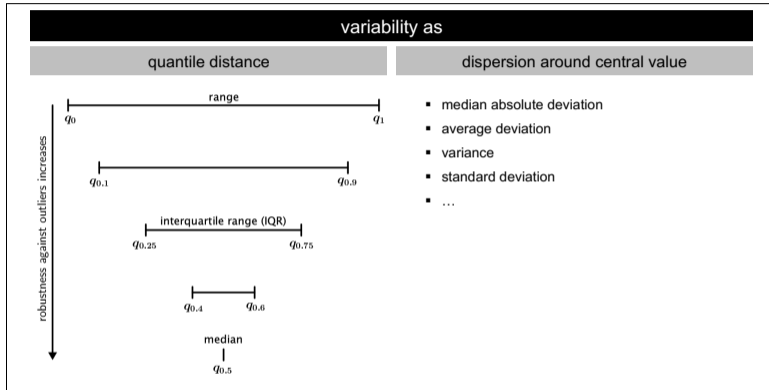


Fig. 1: Variability measures that follow the deviation-of-a-measure of central tendency-concept start from a central tendency (mean or median) as an initial value. In contrast, for quantile distances one can regard the median not as starting point but as a final value of narrowing these distances.

Fostering conceptual understanding of box plots

Stimulus: At two schools A and B, the same number of children answered the question about how many minutes they spend getting to school in the morning. At one of the two schools, there are more children with a trip to school of more than 10 minutes than at the other school. Decide at which one.

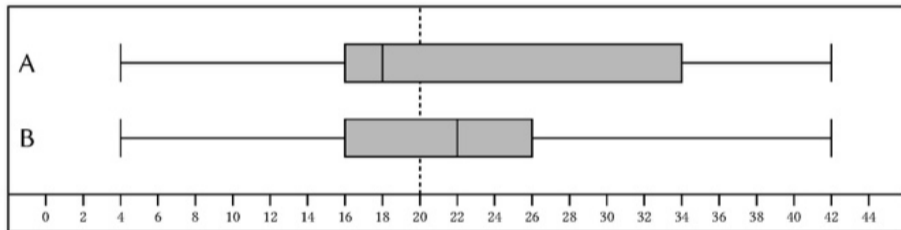


Fig. 3: Although comparing the medians leads to the correct answer (A), students who are influenced by the area misconception consider which box plot shows more area above the critical mark and answer incorrectly (B).

Fostering conceptual understanding of box plots

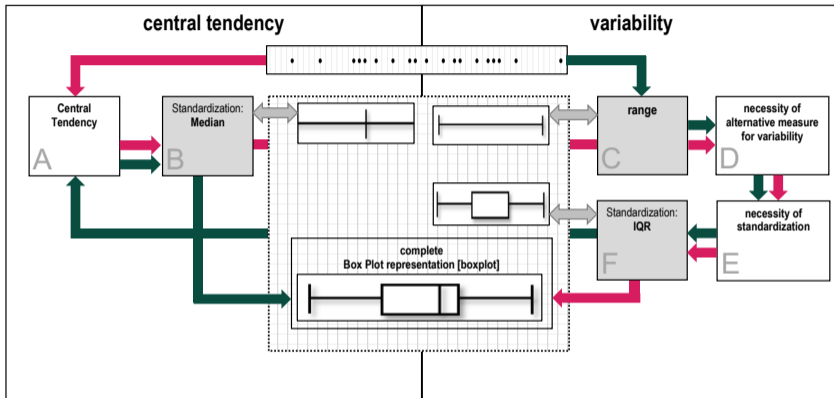


Fig. 5: Learning paths showing two basic approaches to introduce box plots: On the left side the instruction of the IQR (variability) follows that of the median (measure of central tendency), the right side shows the reverse order.

Fostering conceptual understanding of box plots

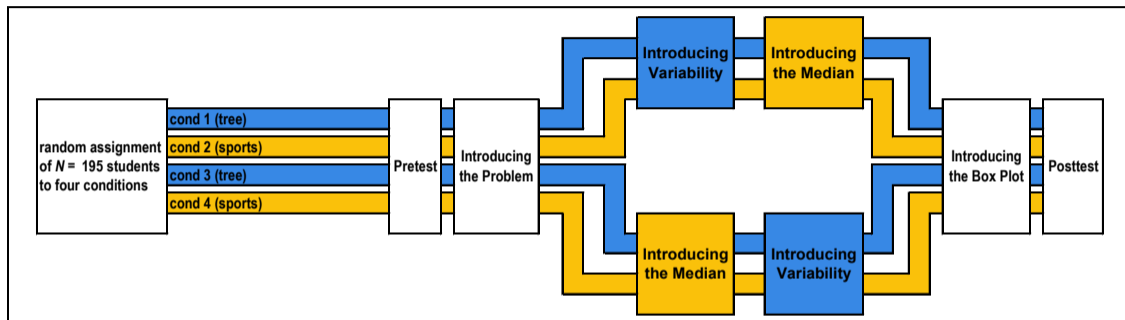
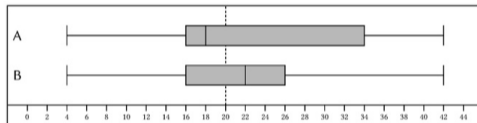


Fig. 6: Procedure of the survey

(Abt et al., submitted)

Fostering conceptual understanding of box plots

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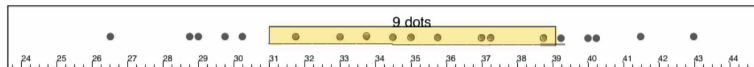
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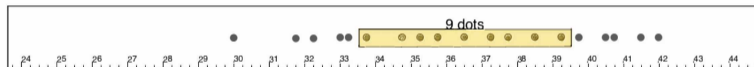
- ☐ school A
- ☐ school B

Fostering conceptual understanding of box plots

In order to decide on a tree species, the city mayor asks you to now compare two tree species in more detail.



maple



large-leaved linden

Task 1: In both diagrams, select an **area of the dot plot** that you would use for your decision. Use the **yellow rectangles** which you can **move** and **change in width**.

Task 2: Which of the two tree species do you think is **better suited** for the avenue? Give reasons for your decision.

My Results

Ready

(Abt et al., submitted)