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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WOG 2023 · Leuven, Belgium
2023, October 11–13

The CoDiL framework

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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

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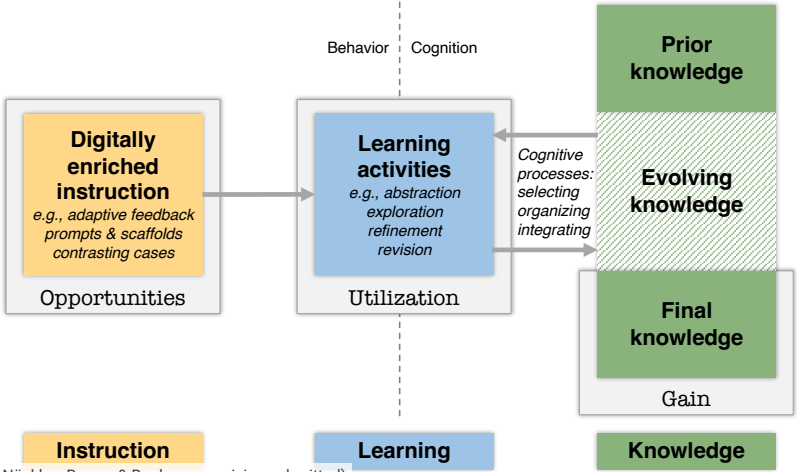
The CoDiL framework



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

Acquiring knowledge components in (digitally-enriched) educational settings

Acquiring knowledge components in educational settings

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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)

Learning activities when learning with digital tools

Learning activities when learning with digital tools

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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

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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)

Linking students' on-task behavior and learning

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Operationalization of cognitive activities via student-tool-interactions

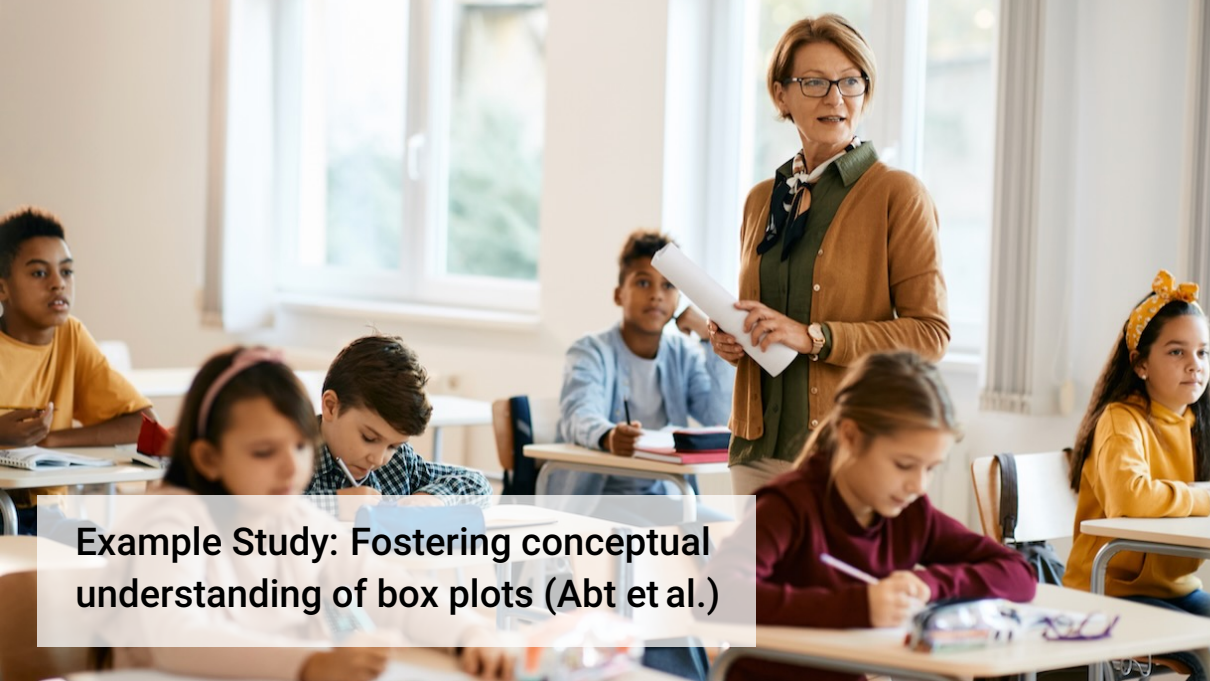
Learning activities link students' **external, behavioral interaction** with the tool and students' **internal, cognitive processes** that lead to knowledge acquisition.

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

Examples of "process data"

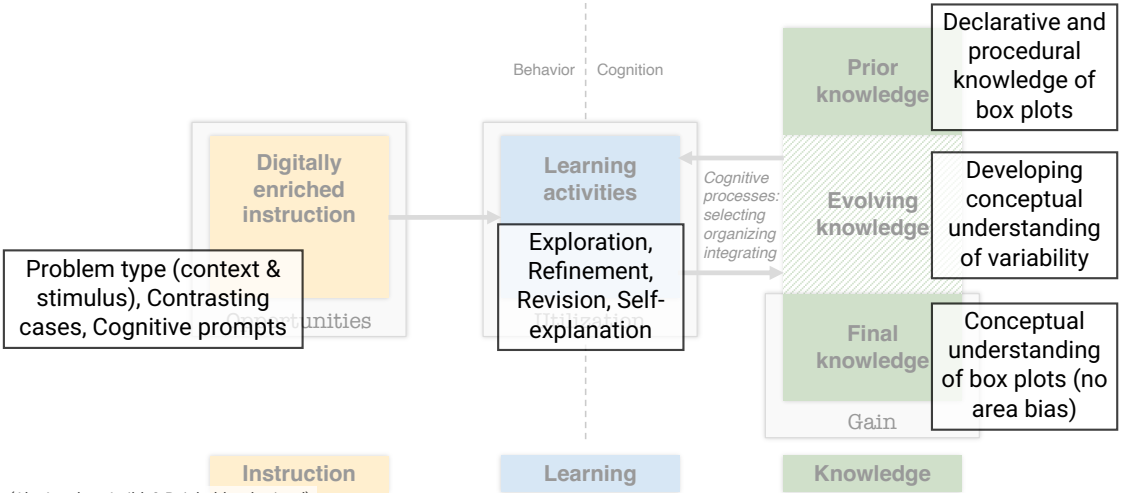
- Student-tool interactions logged unobtrusively by the digital tool itself
- Process indicators obtained from accompanying assessments during learning:
  - Solutions from closed unique cognitive items inside a digital learning path
  - Eye-tracking data
  - Think-aloud protocols accompanying the use 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

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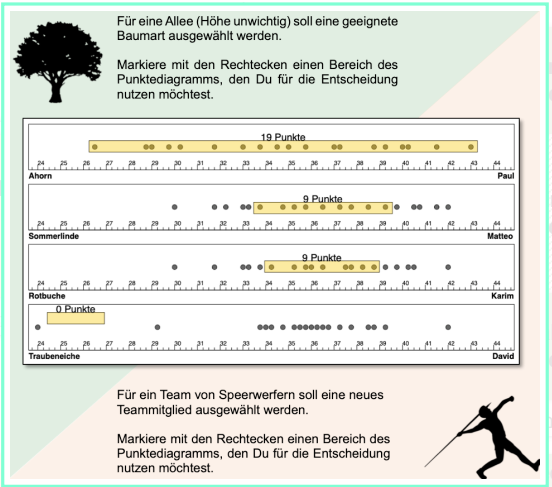
Problem type (context & stimulus), Contrasting cases, Cognitive prompts



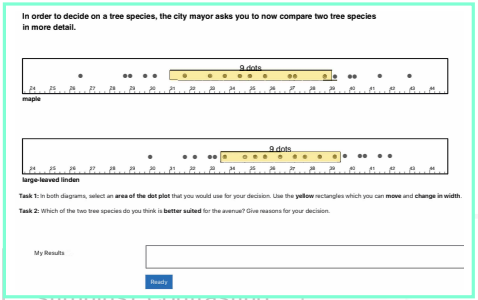
Declarative and procedural knowledge of box plots

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



Behavior | Cognition

Learning activities

Exploration, Refinement, Revision, Self-explanation

Cognitive processes: selecting organizing integrating

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

Instruction | Learning | Knowledge

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

Specifying the CoDiL framework for Martin's study

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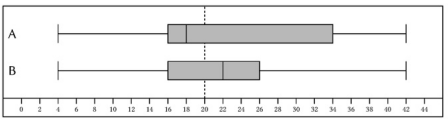
Two schools A and B were attended by equal numbers of children. All children indicated in a survey how long they need to get to school in the morning. Each box plot represents the result for one school.



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.

O school A
O school B

Declarative and procedural knowledge of box plots

Developing conceptual understanding of variability

Conceptual understanding of box plots (no area bias)

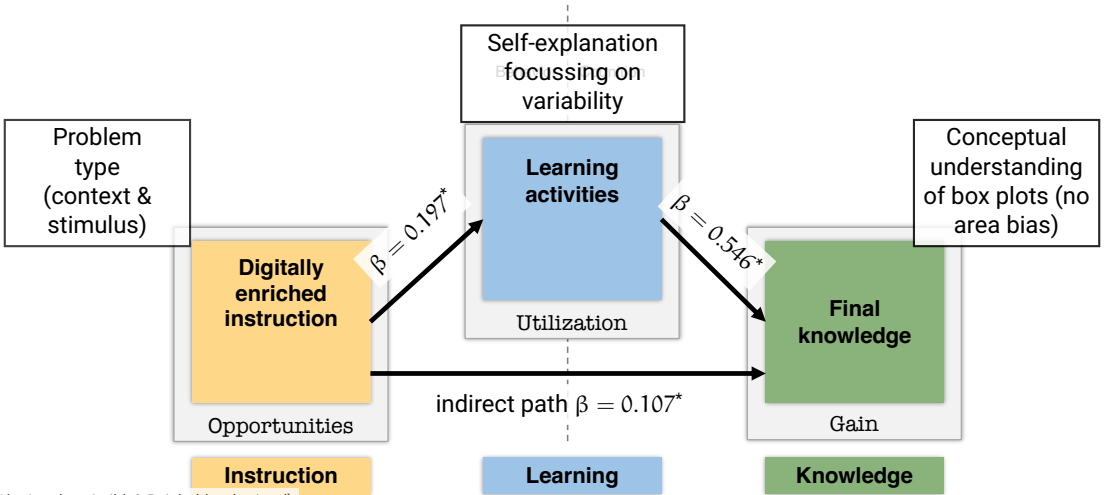
Digitally enriched instruction

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

Instruction

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

Main result from the SEM (controlling for covariates)



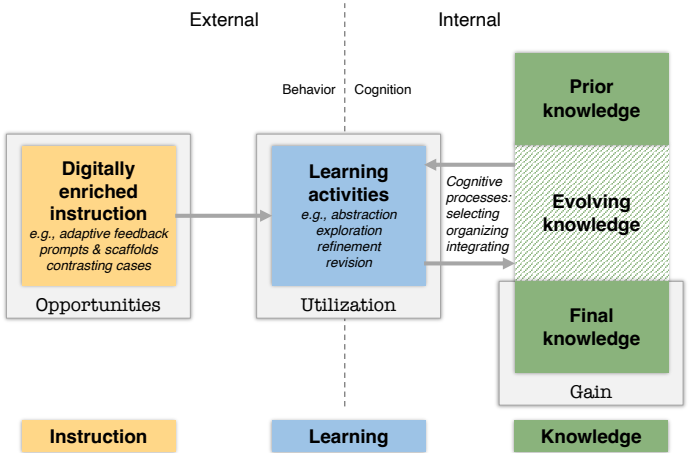
(Abt, Leuders, Loibl, & Reinhold, submitted)

Discussion

Outlook

Reserach 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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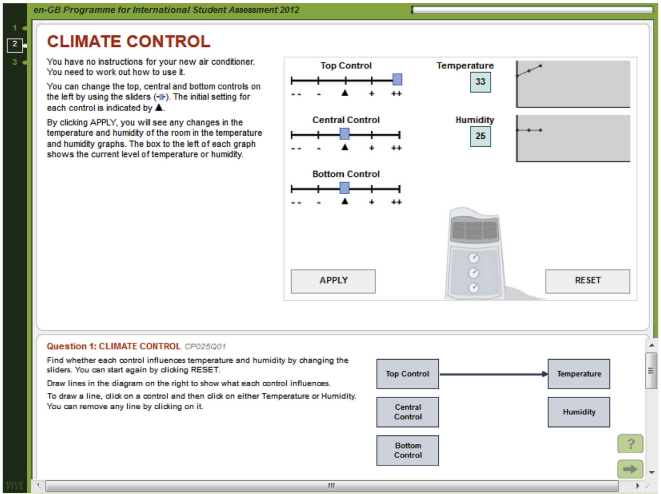
Linking students' on-task behavior and learning



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

Fostering conceptual understanding of box plots

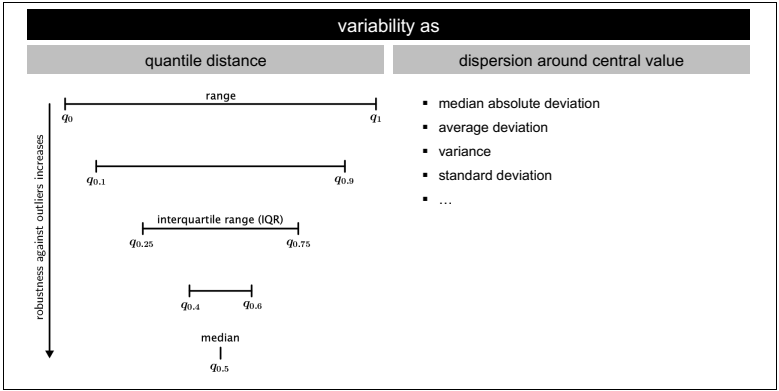


Fig. 1: Variability measures that follow the deviation-of-a-measure of central tendency-concept start from a central tendency (mean or median) as an initial value. In contrast, for quantile distances one can regard the median not as starting point but as a final value of narrowing these distances.

(Abt et al., submitted)

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.

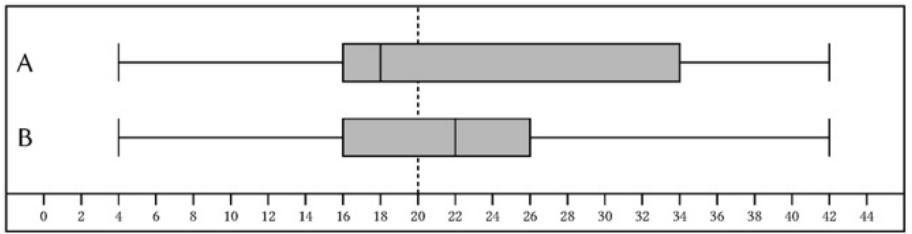


Fig. 3: Although comparing the medians leads to the correct answer (A), students who are influ-enced by the area misconception consider which box plot shows more area above the critical mark and answer incorrectly (B).

(Abt et al., submitted)

Fostering conceptual understanding of box plots

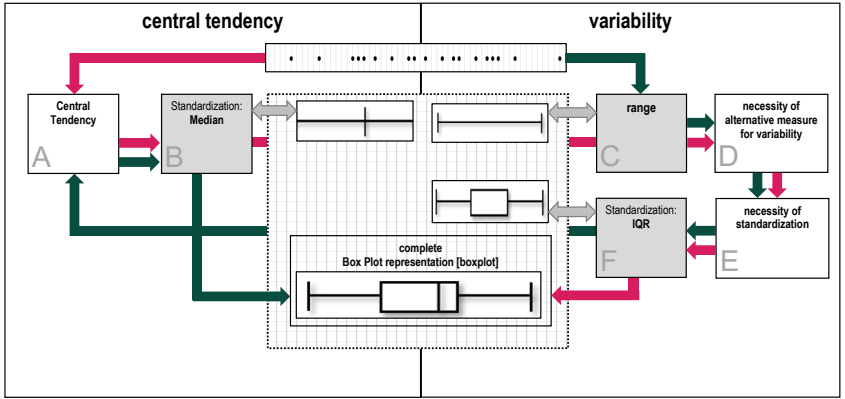


Fig. 5: Learning paths showing two basic approaches to introduce box plots: On the left side the instruction of the IQR (variability) follows that of the median (measure of central tendency), the right side shows the reverse order.

(Abt et al., submitted)

Fostering conceptual understanding of box plots

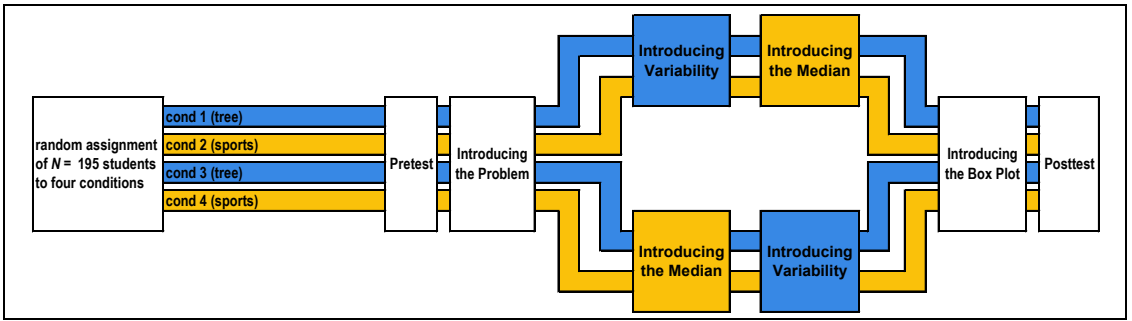


Fig. 6: Procedure of the survey

(Abt et al., submitted)

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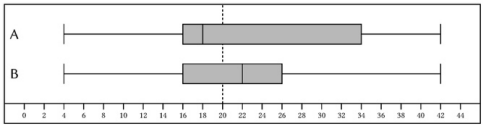

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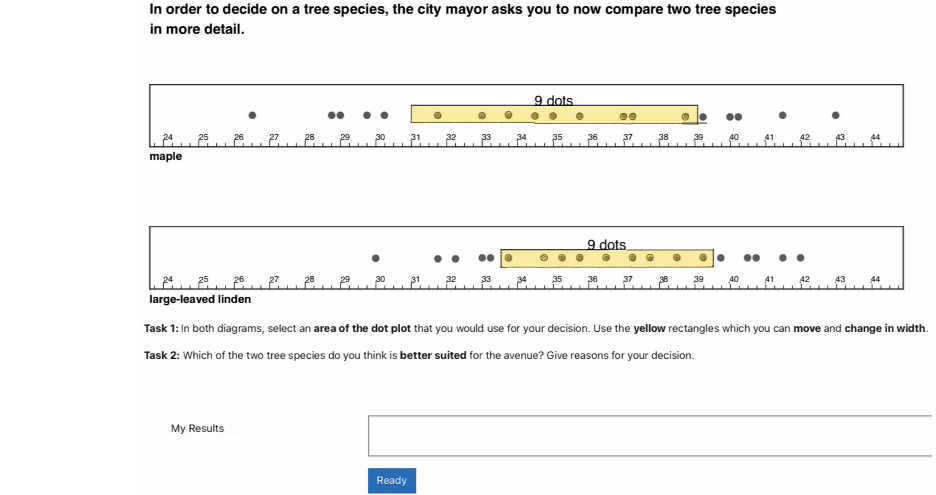

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