Assessing the impact of research-based active-learning materials on student conceptual understanding

Christian H. Kautz

September 06, 2021

Latsis Symposium @ ETH Zürich

TUHH
Hamburg University of Technology

ENGINEERING EDUCATION RESEARCH
FACHDIDAKTIK DER INGENIEUR-WISSENSCHAFTEN

Engineering Education Research Group at the Center for Teaching and Learning (TUHH)

▶ Introduction

Prior research:
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

Christian Kautz

Ferdinand Kieckhäfer

Layla Tulimat

Dimitri Eckert

Clemens Schröter

Max Uzulis

WHAT WE DO:

- Research on conceptual understanding in introductory engineering courses such as *Engineering Mechanics*, *Electric Circuits*, and *Control Theory* (e.g. through interviews)
- Development of instructional materials for these courses on the basis of our research results
- Support for university instructors in implementing these materials
- Research on their effectiveness (e.g. through *Concept Inventories*), including validation of used instruments

- ▶ Introduction
- *Prior research:* Conceptual understanding and Concept Inventories
- *Recent work at TUHH:* Evaluating the effectiveness of instructional materials
- *Open questions:* Identifying general technical skills and introducing AI in assessment

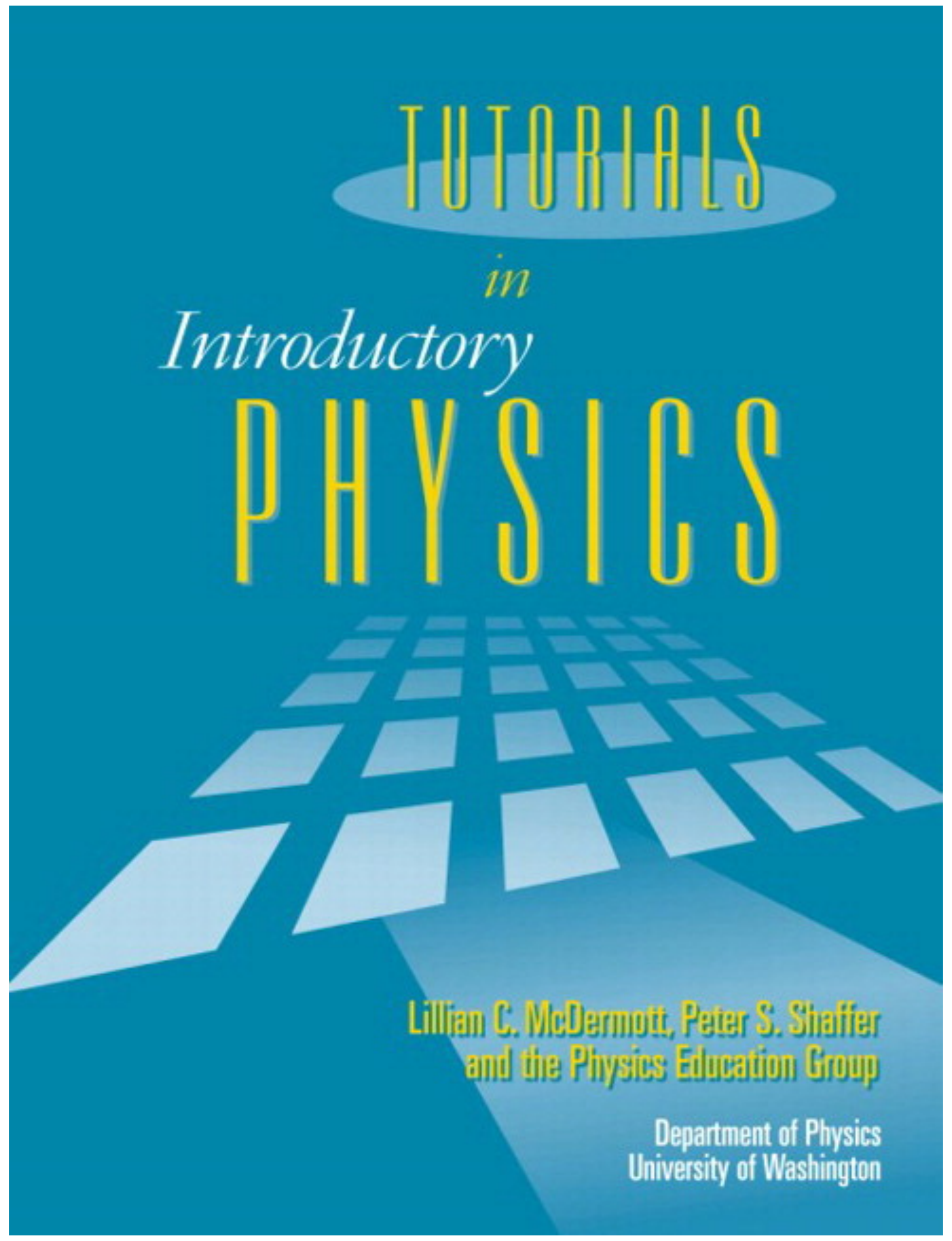
Activating Students in Small-Group Settings
Tutorials (Conceptual Collaborative-Group Worksheets)

- Introduction

Prior research:
Conceptual understanding
and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness
of instructional materials

Open questions:
Identifying general technical skills
and introducing AI in assessment



Physics Education Group
University of Washington
Seattle, WA (USA)

Engineering Education Group
(Abt. f. Fachdidaktik der Ingenieurwissenschaften)
Hamburg University of Technology (TUHH)
Hamburg (Germany)

Images from www.pearson.com, www.pearson.de, and www.springer.com

- Introduction

Prior research:
Conceptual understanding
and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness
of instructional materials

Open questions:
Identifying general technical skills
and introducing AI in assessment

Prior Research:
Identifying Student Conceptual Difficulties and the Development of Concept Inventories

IDENTIFYING CONCEPTUAL DIFFICULTIES IN MECHANICS

Introduction

Prior research:
Conceptual understanding and Concept Inventories

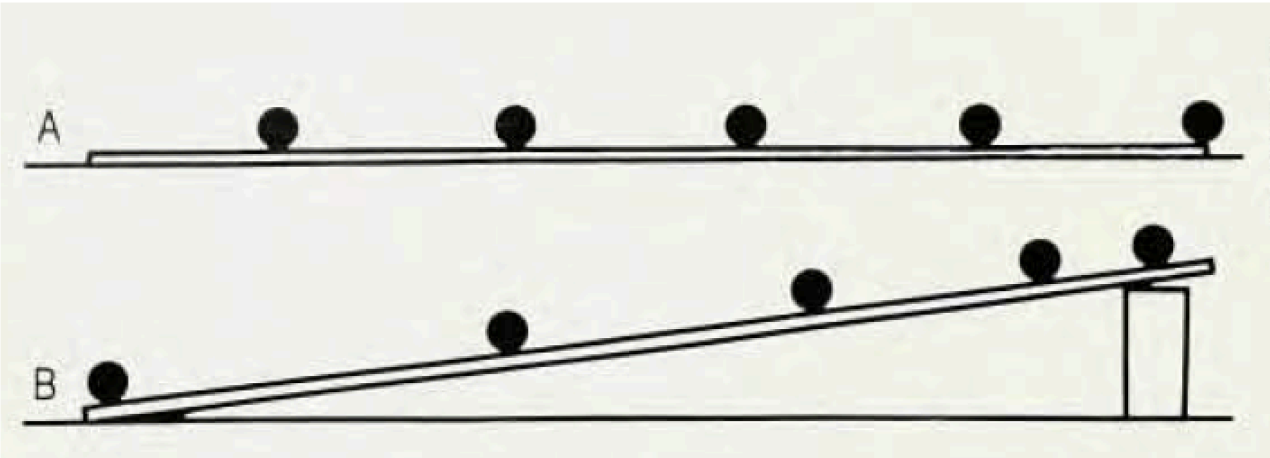
Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

Lillian C. McDermott,
Research on conceptual understanding in mechanics, *Physics Today* **37**, 24 (1984)

TROWBRIDGE & MCDERMOTT (1980, 1981):

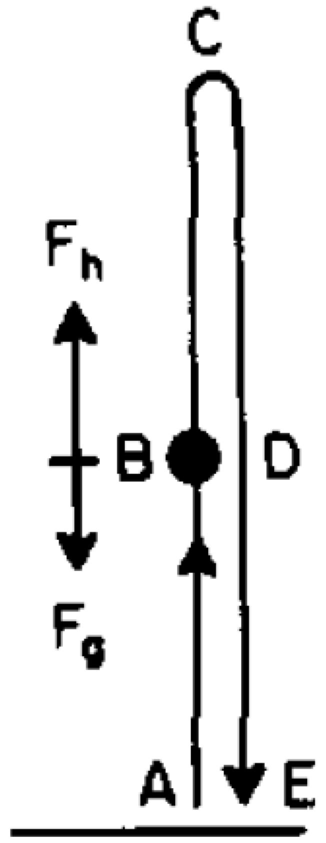
- using "individual demonstration interview" (semi-structured, clinical interview)
- replication and extension of PIAGETian motion tasks
- "position criterion to determine relative velocity"



CLEMENT (1982)

- using written test and problem solving interviews
- "motion implies a force" preconception

similar work by DISESSA; DRIVER; MINSTRELL; SJØBERG; VIENNOT.



DEVELOPING A CONCEPTUAL DIAGNOSTIC TEST: THE FORCE CONCEPT INVENTORY

Introduction

▶ *Prior research:*
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

HESTENES et al. ([1985], 1992, 1995)

- 6 key Newtonian concepts related to force
- 29-item multiple-choice test
- inventory referred to as a “probe of belief systems”
- almost one-to-one correspondence
  - items to concepts
  - distractors to misconceptions
- sample item (# 13 [FCI29])
  - *Third Law* (for continuous forces)
  - “most active agent produces greatest force” (N2 vs. N3)

D. Hestenes, M. Wells & G. Swackhamer, Force Concept Inventory, *The Physics Teacher* **30**, 141 (1992).

Development of Concept Inventories in Engineering (2000 – 2004)

Introduction

Prior research:
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

https://web.archive.org/web/20040602200017/http://www.foundationcoalition.org/home/keycomponents/concept/index.html

- eight "engineering coalitions" funded by US National Science Foundation
- *Foundation Coalition (FC)* subprojects focusing on foundational years in the engineering curriculum
- many including CI development
- mostly started in 2000; *FC* website in 2004 lists 12 CIs in: Thermodynamics; Strength of materials; Signals and systems; Electromagnetics; Circuits; Fluid mechanics; Materials; Chemistry; Dynamics, Heat transfer; Computer engineering; Electronics.
- development seems to have slowed down once funding ended

Using Concept Inventories to Measure the Effectiveness of Teaching: The Normalized Gain

Introduction

▶ *Prior research:*
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

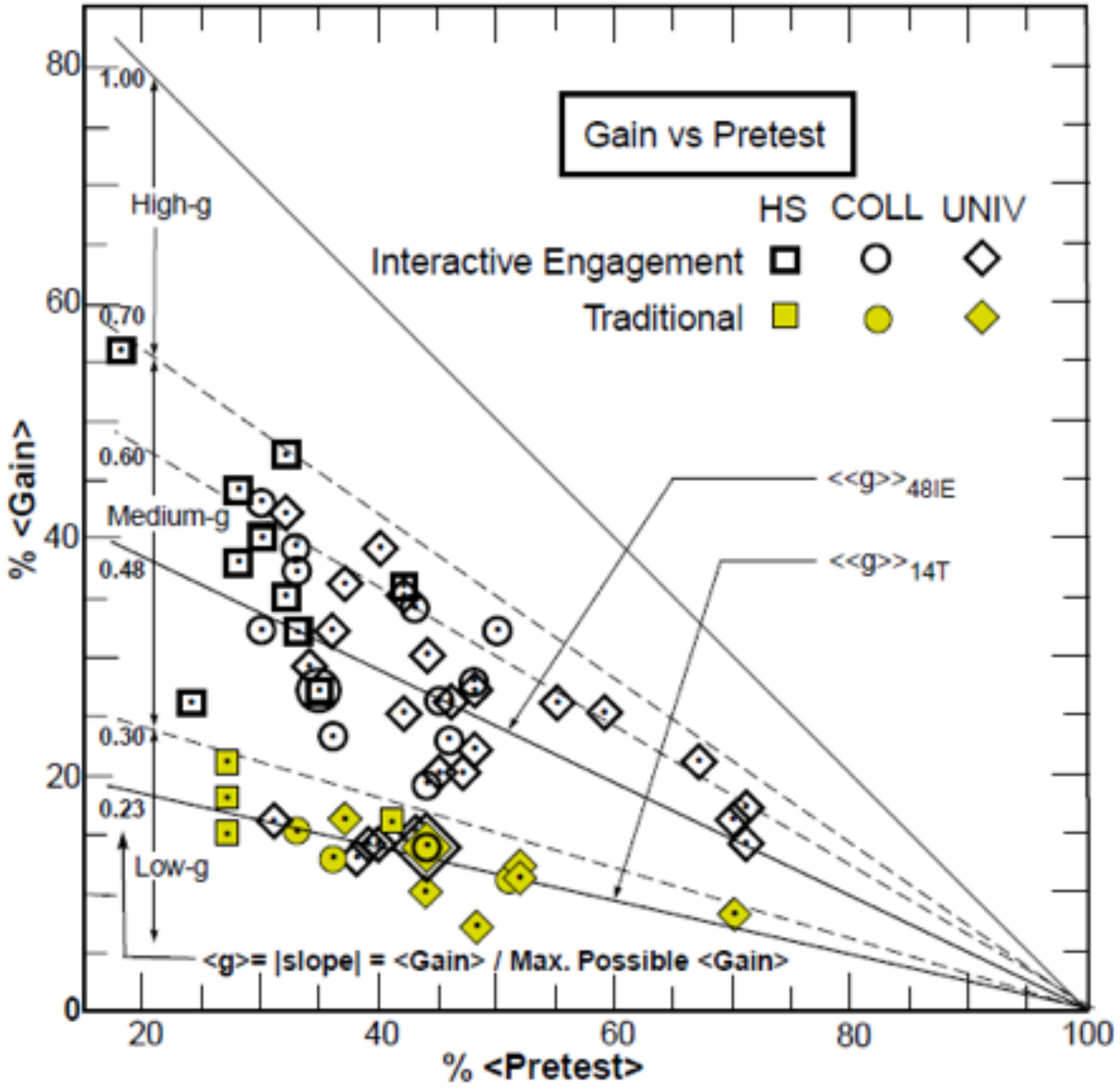
Hake, R.; „Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. Am. J. Physics 66, 64-74 (1998).

Hake (1998)

- data from 62 US high-school, college and university courses
- total *N* = 6542 students
- normalized learning gain:

$$g = \frac{\left(x_{\text{post}} - x_{\text{pre}}\right)}{\left(1 - x_{\text{pre}}\right)}$$

- g ≈ 0.23 (± 0.04) for trad., g ≈ 0.48 (± 0.14) for interact. instruction



Introduction

▶ *Prior research:*
Conceptual understanding
and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness
of instructional materials

Open questions:
Identifying general technical skills
and introducing AI in assessment

RECENT WORK AT TUHH:
ASSESSMENT OF CONCEPTUAL UNDERSTANDING FOR THE EVALUATION OF INSTRUCTIONAL MATERIALS IN ENGINEERING MECHANICS

ADDED CHALLENGE IN ENGINEERING COURSES: USING NON-IDENTICAL PRE- AND POST-TESTS

- Strength of FCI and similar tests in introductory physics (including mechanics, electricity, optics)
  - items use scenarios from everyday life (more or less)
  - virtually no technical language or symbolism necessary
  - items can be *interpreted* correctly by novices
  - tests can be administered as pre-tests
- in most introductory engineering courses, some technical terminology and formalism is introduced (FBDs, circuit symbols, block diagrams)
  - instruments that are useful as post-tests are not valid when used as pre-tests

➡ non-identical pre- and post-tests (NIPPs)

➡ normalised learning gain cannot be used

Direnga et al. Refining the WLR: Quantifying the difference in learning success between courses, Proceedings of REES 2017.

Interpreting Results of Non-Identical Pre- and Post-Tests

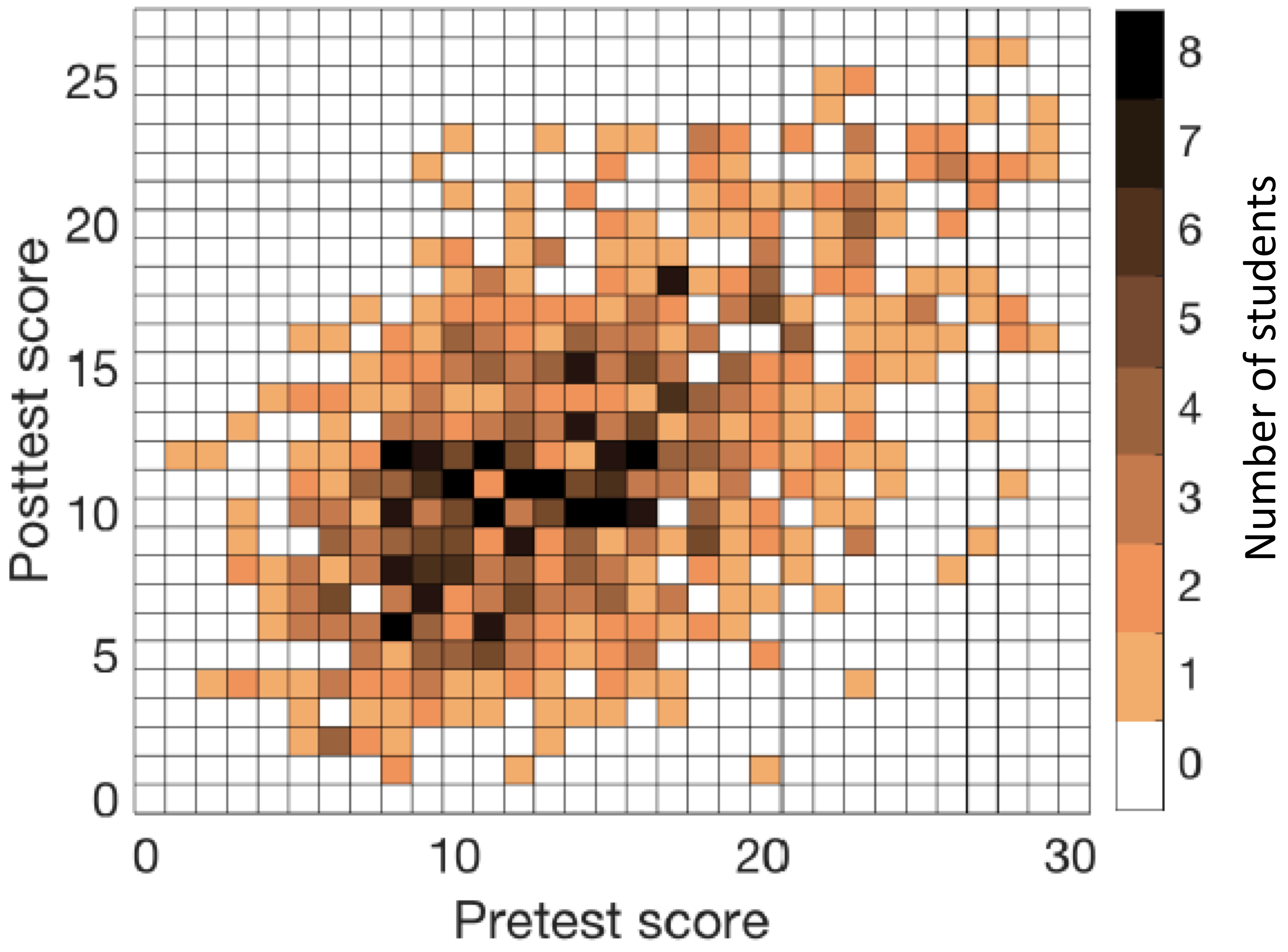
Introduction

Prior research:
Conceptual understanding and Concept Inventories

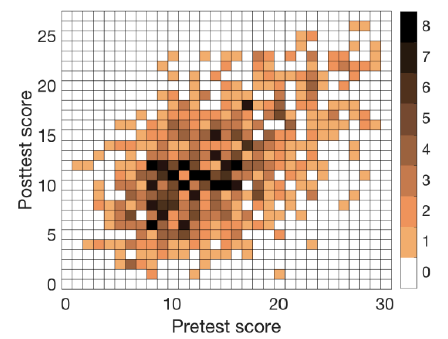
▶ *Recent work at TUHH:*
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

J. Direnga, D. Timmermann, F. Kieckhäfer, and C. Kautz, ‘Refining the WLR: Quantifying the difference in learning success between courses’, in *Research in Engineering Education Symposium 2017 (REES2017)*, Bogotá, Columbia, 2017.



Weighted Linear Regression
“Discriminative Gain”



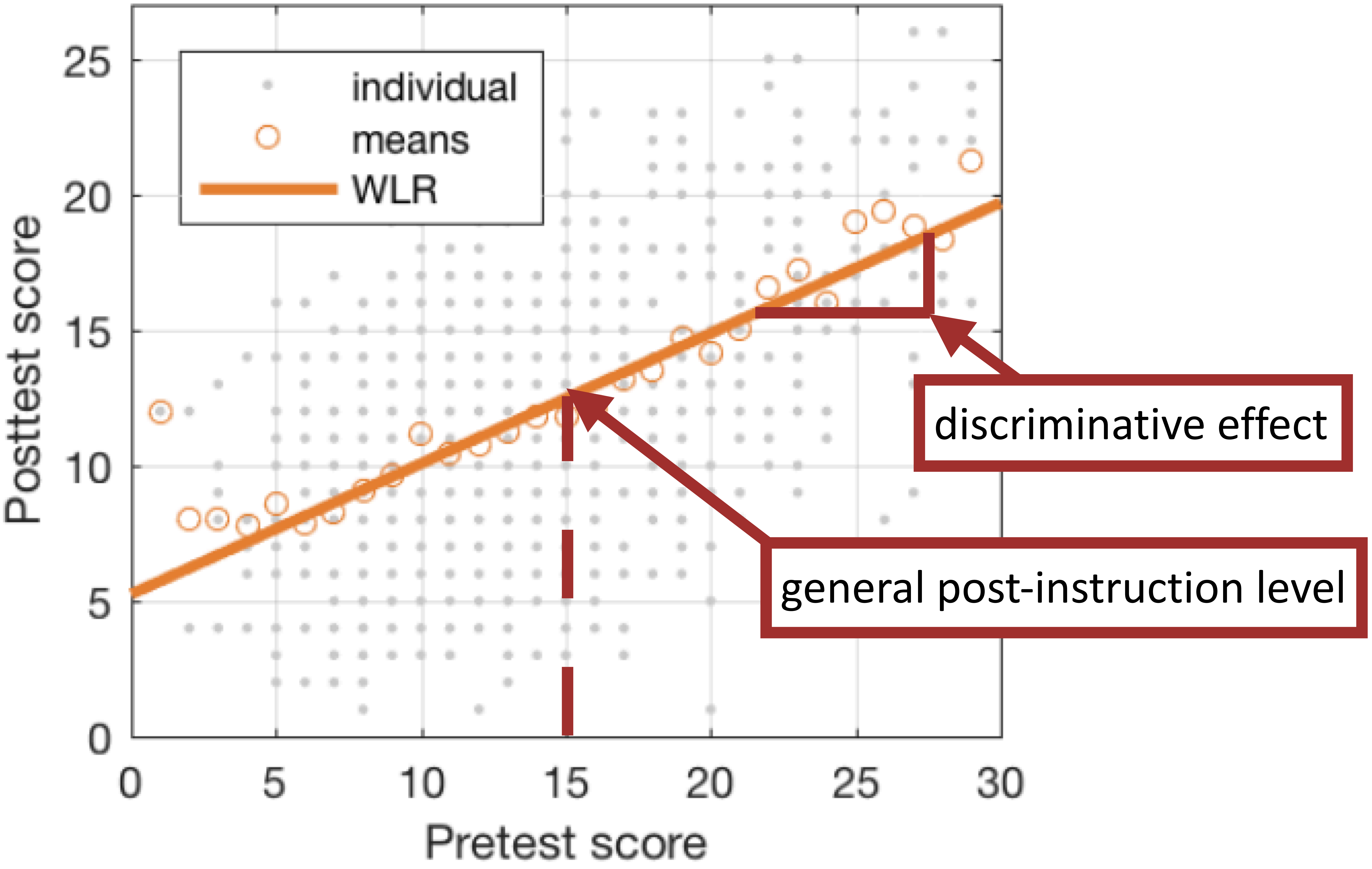
Introduction

Prior research:
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

J. Direnga, D. Timmermann, F. Kieckhäfer, and C. Kautz, ‘Refining the WLR: Quantifying the difference in learning success between courses’, in *Research in Engineering Education Symposium 2017 (REES2017)*, Bogotá, Columbia, 2017.



Effectiveness of Tutorials (conceptual collaborative-group worksheets)

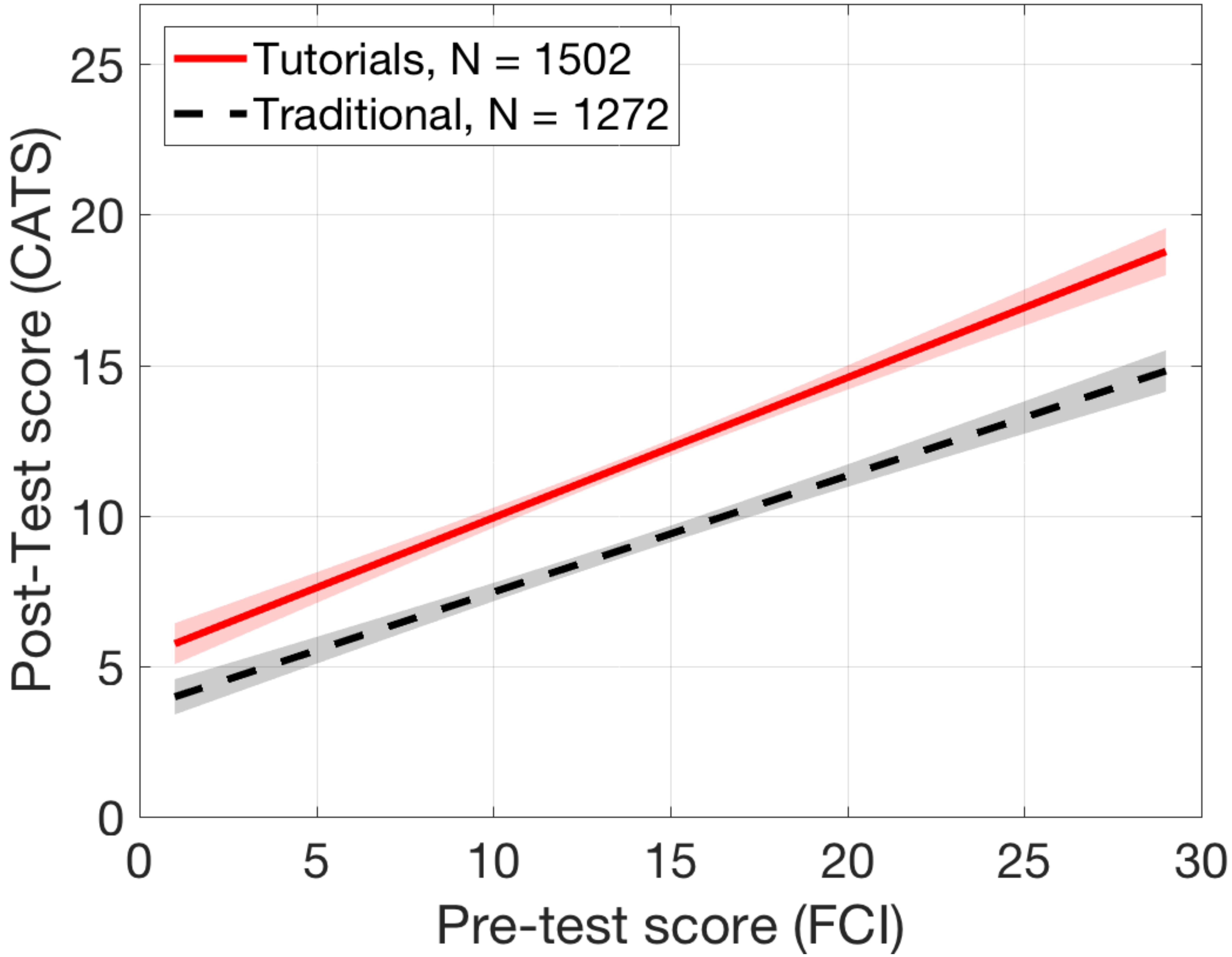
Introduction

Prior research:
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

J. Direnga, Assessing the Effectiveness of Research-Based Active Learning Materials for Introductory Engineering Mechanics, 2021.



- General post-instruction level: + 2,9 pts
- Discriminative effect: + 0,08 pts/pt
- No overlap

Introduction

Prior research:
Conceptual understanding and Concept Inventories

▶ *Recent work at TUHH:*
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

Open Questions:

- *Identifying General Basic Skills in Technical Fields*
- *Using Artificial Intelligence in STEM Education*

Identifying *General* Basic Skills in Technical Fields

- Are there general basic engineering skills that are …
  - … *more general* than those applying to specific subjects (mechanics, electrical circuits, thermodynamics, control theory)?
  - … *more discipline-specific* than general academic key competences (self-regulatory skills such as time management etc., study skills, interpersonal skills)?
- If so, to what extent are these *mathematical* in nature?
- If mathematical in nature, are these skills developed in typical mathematics instruction? Are they more about a physicist's or engineer's (rather than mathematicians) way of using mathematics?

ADAPTIVE GENERATION OF TASKS FOR CONCEPTUAL LEARNING AND ASSESSMENT

- Can an automated system create *new* tasks that …
  - … test for (or help to develop) conceptual understanding ?
  - … are not merely variations of existing tasks by variation of order or value of given variables?
- How do we represent conceptual understanding in a form that can be read by a machine?
- Can a (machine-readable) ontology that uses an underlying taxonomy of learning outcomes (such as Bloom's taxonomy) help?

THANK YOU FOR YOUR ATTENTION!

Effectiveness of Tutorials: Does Time play a role?

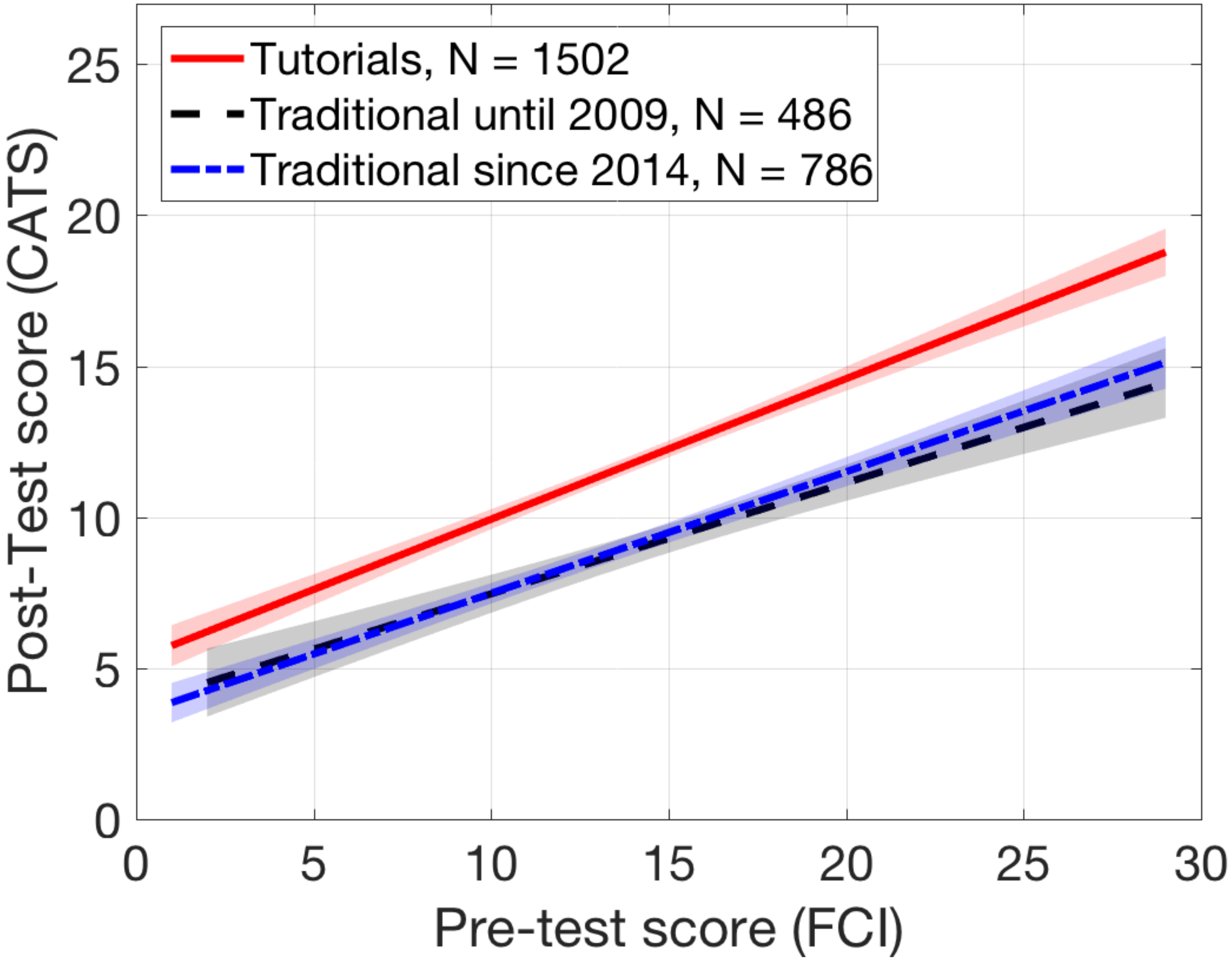
Introduction

Prior research:
Conceptual understanding and Concept Inventories

▶ *Recent work at TUHH:*
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

J. Direnga, Assessing the Effectiveness of Research-Based Active Learning Materials for Introductory Engineering Mechanics, 2021.



No distinction between earlier and later years of traditional instruction

EFFECTIVENESS OF TUTORIALS:
HOW STRONGLY DO RESULTS DEPEND ON THE INSTRUCTOR?

Introduction

Prior research:
Conceptual understanding and Concept Inventories

Recent work at TUHH:
Evaluating the effectiveness of instructional materials

Open questions:
Identifying general technical skills and introducing AI in assessment

J. Direnga, Assessing the Effectiveness of Research-Based Active Learning Materials for Introductory Engineering Mechanics, 2021.