GAANN Seminar
UNC-Charlotte

Investigating and improving the models of programming concepts held by novice programmers

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INTRODUCTION

- Computer programming education is still a major challenge
- ITiCSE working group ("McCracken group") study
  - Low preparedness
  - Poor performance
  - High dropout rates

INTRODUCTION

- Computer programming education is still a major challenge

- Sources of weakness:

  - Problem-solving ability [1]

  - Non-viable mental models of key concepts [2,3]

[1] Barnes, Fincher, & Thompson, 1997
[2] Bayman & Mayer, 1983
[3] Lui, Kwan, Poon, & Cheung, 2004

INTRODUCTION

- Computer programming education is still a major challenge
- Addressing the deficiencies:
    - Preliminary study of novice students’ mental models
    - 3 studies using constructivist learning model with cognitive conflict and visualization
    - Evaluation of results

BACKGROUND

- Mental Models
  - Craik (1943): small-scale models of reality
  - Johnson-Laird (1983): working memory constructs
  - Gentner and Stevens (1983): long-term memory
  - Schwartz & Black (1996): long-term models may influence the working models

BACKGROUND

- Mental Models of novice programmers
  - Bayman and Mayer (1983): models of computer activity for BASIC statements
  - Kahney (1983): loop or copy models of recursion
  - Gotschi, Sanders, and Galpin (2003): loop or copy models of recursion
  - **Dehnadi and Bornat** (2006): mental models for assignment statements
  - Caspersen, Bennedsen, and Larsen (2007): could not replicate the previous work

BACKGROUND

- Difficulties of novice programmers - du Boulay (1989)

1. Orientation - what is programming for

2. Notional Machine - general properties

3. Notation - syntax and semantics

4. Structure - patterns and schemas

5. Pragmatics - specify, develop, test, debug

BACKGROUND

- Difficulties of novice programmers - du Boulay (1989)

1. Orientation
2. Notional Machine
3. Notation
4. Structure
5. Pragmatics

BACKGROUND

- Constructivism
  - Alternative to objectivism - a single objective truth to transfer to students' minds
  - Learners actively construct knowledge by combining the experiential world with existing cognitive structures
  - A key strategy - **cognitive conflict**
    - explicitly challenging pre-existing ideas
    - form appropriate, viable mental models

BACKGROUND

- Cognitive conflict
  - A number of supporting results
    - Baser (2006) - heat and temperature content in physics
    - Demircioglu, Ayas, and Demircioglu (2005) - acids and bases in chemistry
  - Some alternative results
    - Limon (2001) - suggested a range of effects

MOTIVATING STUDY

Investigating the viability of mental models held by novice programmers

MOTIVATING STUDY

- Motivated by Dehnadi & Bornat's controversial study
- Examining mental models of value and reference assignment in novice Java programmers
- 90 participants
  - from an object-oriented programming course using "objects first" approach
  - studied near the end of the course
  - Questionnaire under examination conditions

MOTIVATING STUDY

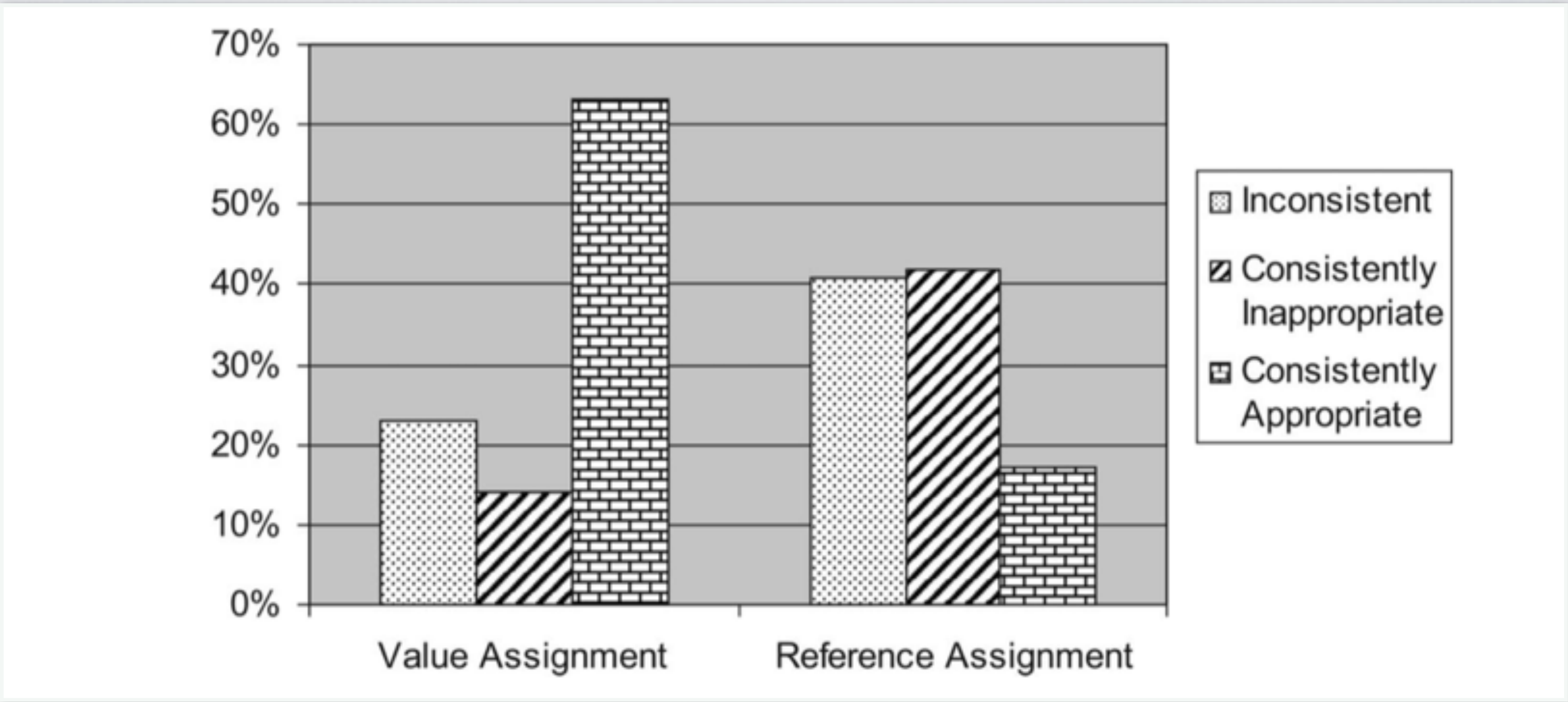
- Questionnaire format
    - open-ended questions
        - describe the execution of a small program fragment
        - use text or diagrams
        - designed to reveal mental models
    - multiple choice questions (12)
        - predict the result of a small program fragment
        - predefined answers mapped to mental models
    - examined questions related to value- and reference-based assignments

MOTIVATING STUDY

- Questionnaire results
    - open-ended questions
        - 25 (of 90) - too brief or unclear to categorize
        - 11 - clearly used appropriate mental models
        - 54 - at least one inappropriate model
            - non-viable reference models more common

MOTIVATING STUDY

- Questionnaire results
  - MC questions



MOTIVATING STUDY

- Questionnaire results
  - Compared results with course grades
    - appropriate models correlated with good performance
    - inappropriate models correlated with bad performance
  - 1/3 of students held non-viable models of value assignment
  - 5/6 of students held non-viable models of reference assignment

PROPOSED MODEL

A learning model integrating cognitive conflict strategy and program visualization

PROPOSED MODEL

- Building viable mental models of programming concepts is hard
  - information to confirm or contradict models is not easily available
- Visualizations can aid construction of mental models of abstract phenomena, however —
  - most tools are based on objectivist models
  - they don't let students explore their own conceptions
  - students satisfied with their pre-existing concepts tend not to accept new ones

PROPOSED MODEL

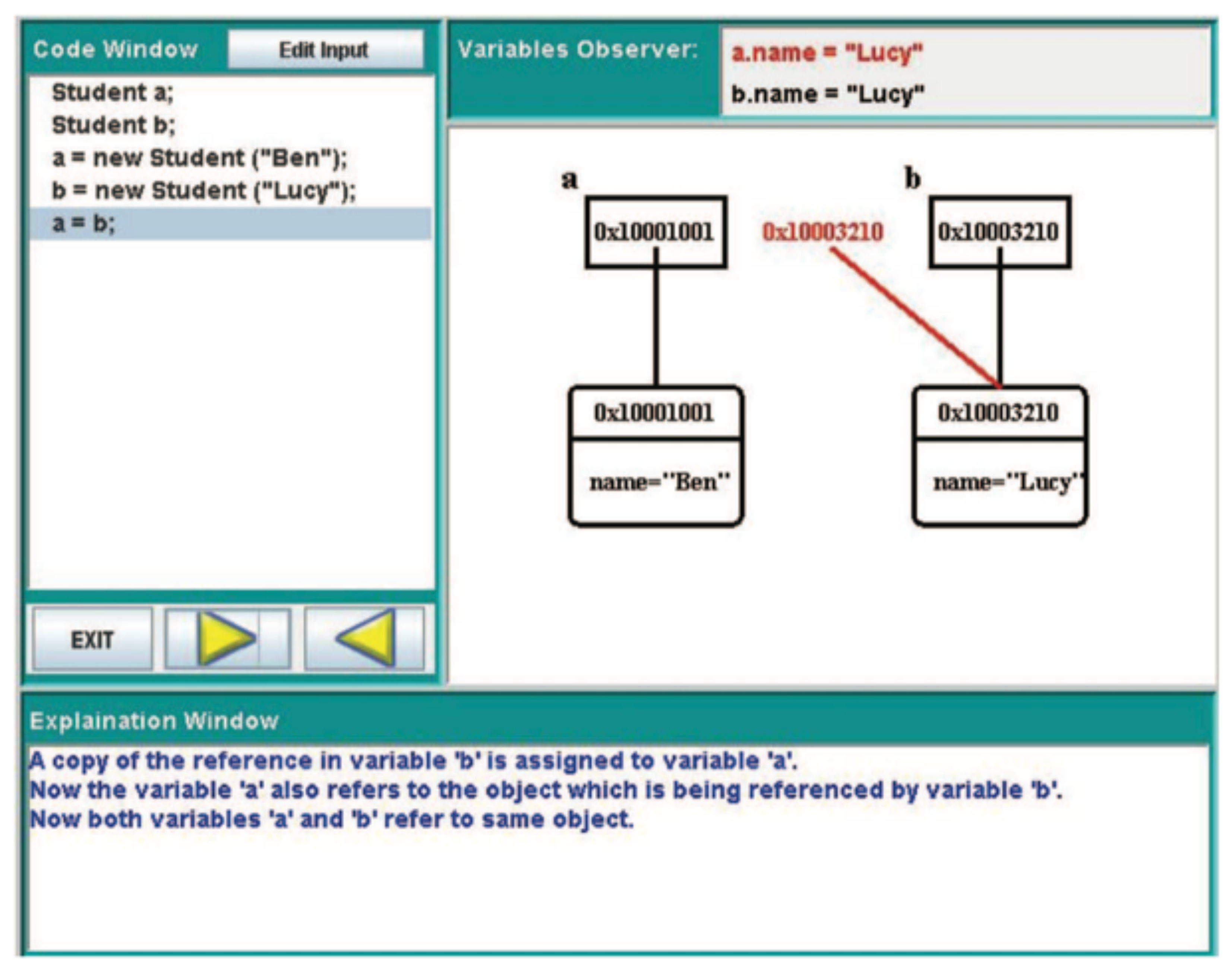
- General idea:
  - employ cognitive conflict
  - support construction of viable models using a visualization environment

PROPOSED MODEL

- Proposed teaching model
  1. Preliminary stage - investigate pre-existing mental models
  2. Cognitive conflict stage - challenge pre-existing models
  3. Model construction stage - construct viable models with visualization and animation
  4. Application stage - reinforce models with applied problems

PROPOSED MODEL

- Visualization tool:
  - step-by-step execution
  - textual descriptions



```
Student a;
Student b;
a = new Student ("Ben");
b = new Student ("Lucy");
a = b;
```

a.name = "Lucy"
b.name = "Lucy"

A copy of the reference in variable 'b' is assigned to variable 'a'.
Now the variable 'a' also refers to the object which is being referenced by variable 'b'.
Now both variables 'a' and 'b' refer to same object.

STUDY A

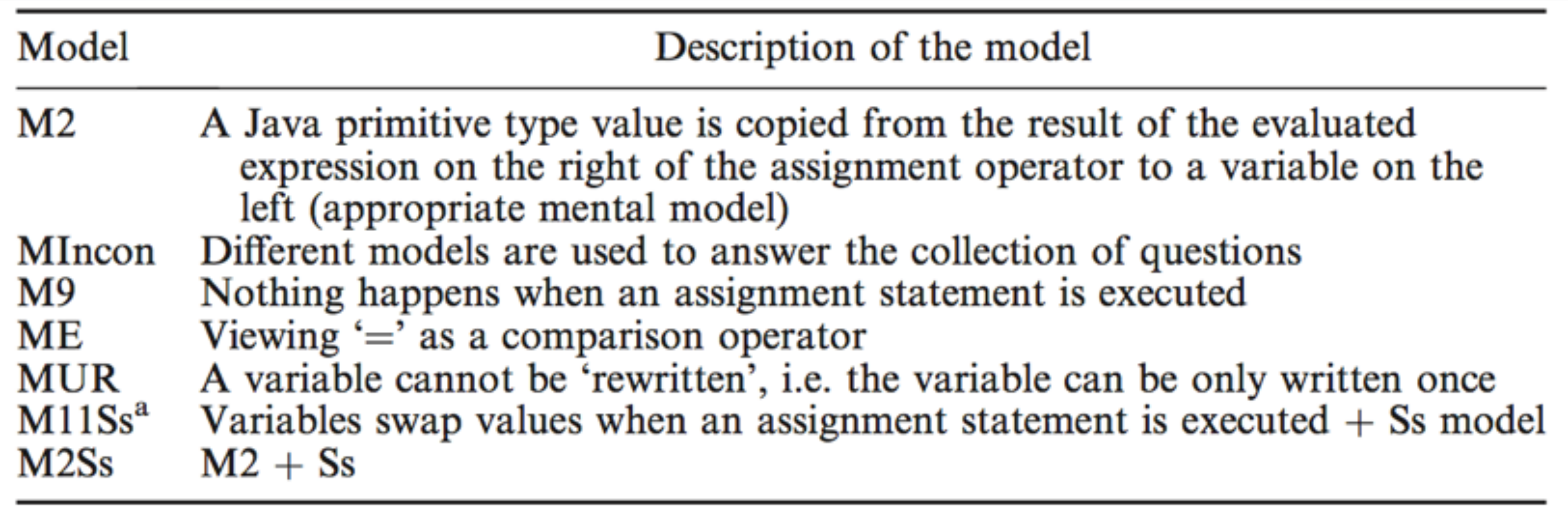
- Focus on value assignment

- 60 participants
  - from freshman Java course
  - after value assignment had been taught

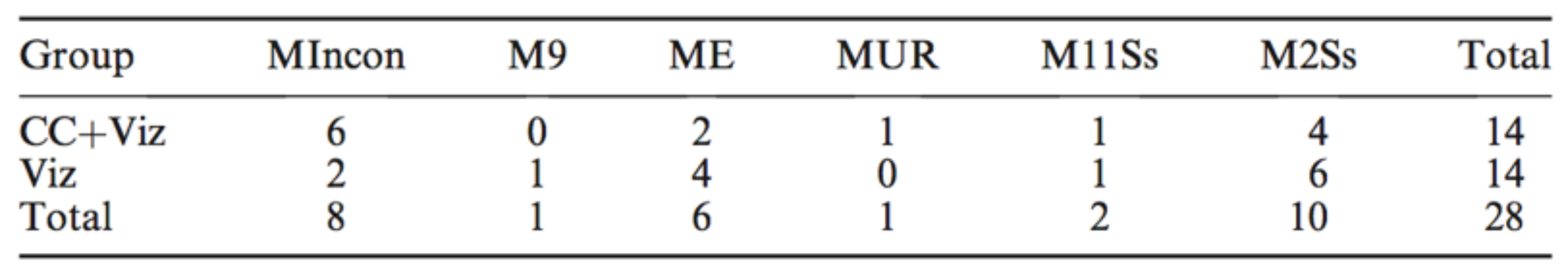
- Preliminary pre-test to identify models
- Students with non-viable models (38) sorted into two groups
  - Cognitive conflict and visualization
  - Visualization only
- Post-test to investigate model results

STUDY A

- Results
    - Pre-test identified a number of mental models

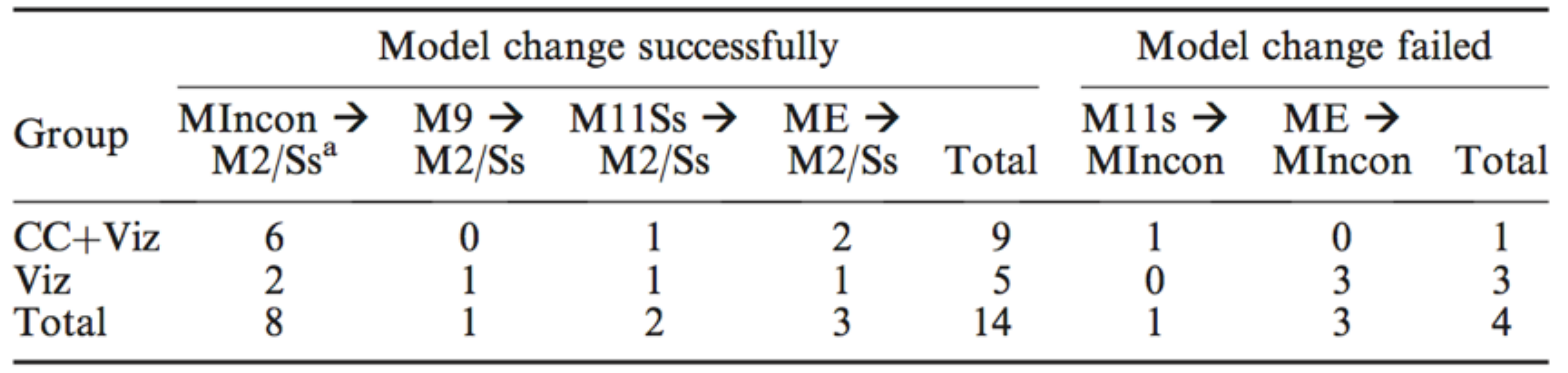


Model	Description of the model
M2	A Java primitive type value is copied from the result of the evaluated expression on the right of the assignment operator to a variable on the left (appropriate mental model)
MIncon	Different models are used to answer the collection of questions
M9	Nothing happens when an assignment statement is executed
ME	Viewing '=' as a comparison operator
MUR	A variable cannot be 'rewritten', i.e. the variable can be only written once
M11Ss[a]	Variables swap values when an assignment statement is executed + Ss model
M2Ss	M2 + Ss

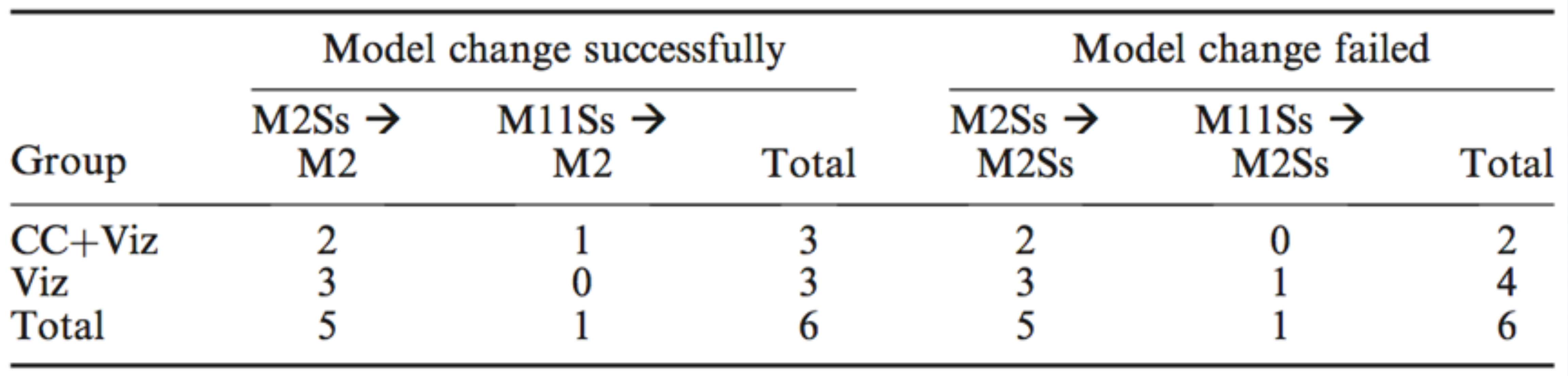


Group	MIncon	M9	ME	MUR	M11Ss	M2Ss	Total
CC+Viz	6	0	2	1	1	4	14
Viz	2	1	4	0	1	6	14
Total	8	1	6	1	2	10	28

STUDY A



Group	Model change successfully					Model change failed		
	MIncon → M2/Ss[a]	M9 → M2/Ss	M11Ss → M2/Ss	ME → M2/Ss	Total	M11s → MIncon	ME → MIncon	Total
CC+Viz	6	0	1	2	9	1	0	1
Viz	2	1	1	1	5	0	3	3
Total	8	1	2	3	14	1	3	4

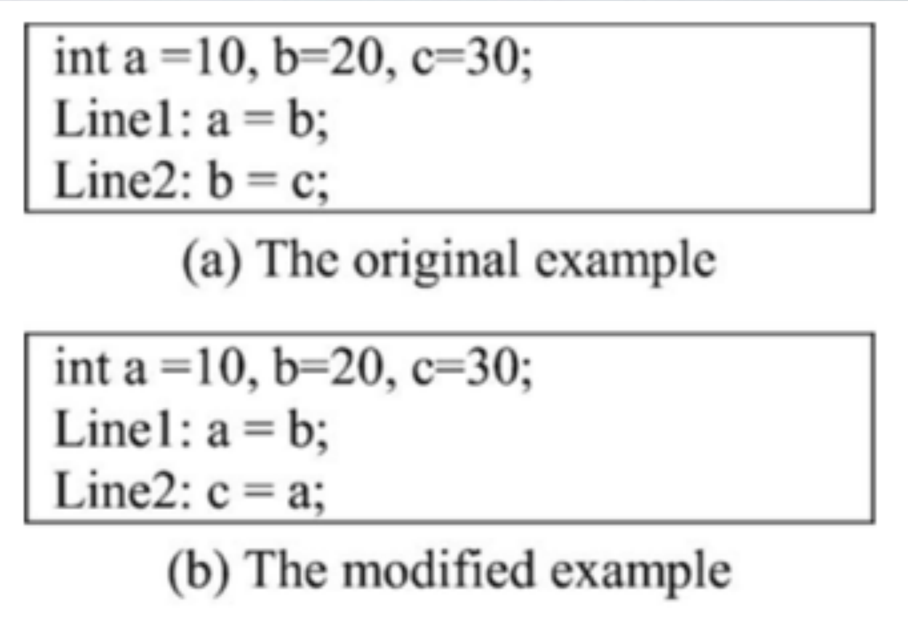


Group	Model change successfully			Model change failed		
	M2Ss → M2	M11Ss → M2	Total	M2Ss → M2Ss	M11Ss → M2Ss	Total
CC+Viz	2	1	3	2	0	2
Viz	3	0	3	3	1	4
Total	5	1	6	5	1	6

STUDY A

- Discussion
  - No significant difference between treatments (p = 0.13)
  - Visualization tool helped students challenge pre-existing model and develop viable mental models
  - Visualization tool was helpful for assignment, but not so much for execution flow
    - tool might not directly challenge all models of flow

STUDY B



```
int a =10, b=20, c=30;
Line1: a = b;
Line2: b = c;
```

(a) The original example

```
int a =10, b=20, c=30;
Line1: a = b;
Line2: c = a;
```

(b) The modified example

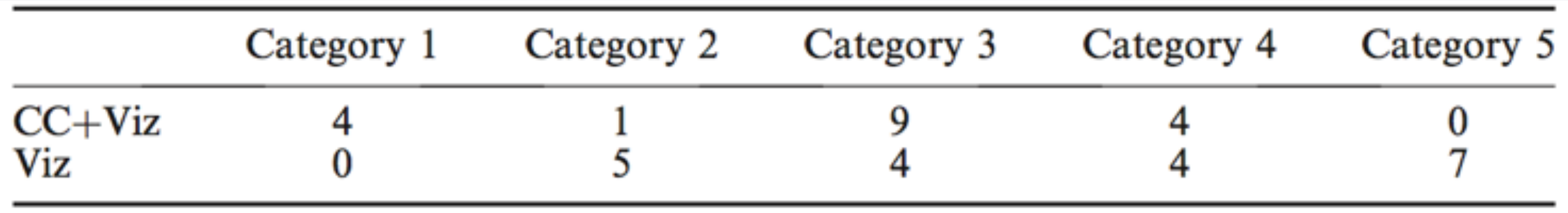
- Focus on reference assignment

- 43 participants
  - from same freshman Java course
  - after reference assignment had been taught

- Preliminary pre-test to identify models
- Students with non-viable models (41) sorted into two groups
  - Cognitive conflict and visualization
  - Visualization only
- Post-test to investigate model results and feedback questionnaire

STUDY B

- Results
  - Participants organized into categories after completing study
    - Category 1: became comfortable with the questions and concepts
    - Category 2: improved understanding of reference
    - Category 3: improved understanding of supporting concepts (but not reference)
    - Category 4: realized their understanding was flawed, but did not change understanding
    - Category 5: did not realize understanding was flawed



	Category 1	Category 2	Category 3	Category 4	Category 5
CC+Viz	4	1	9	4	0
Viz	0	5	4	4	7

STUDY B

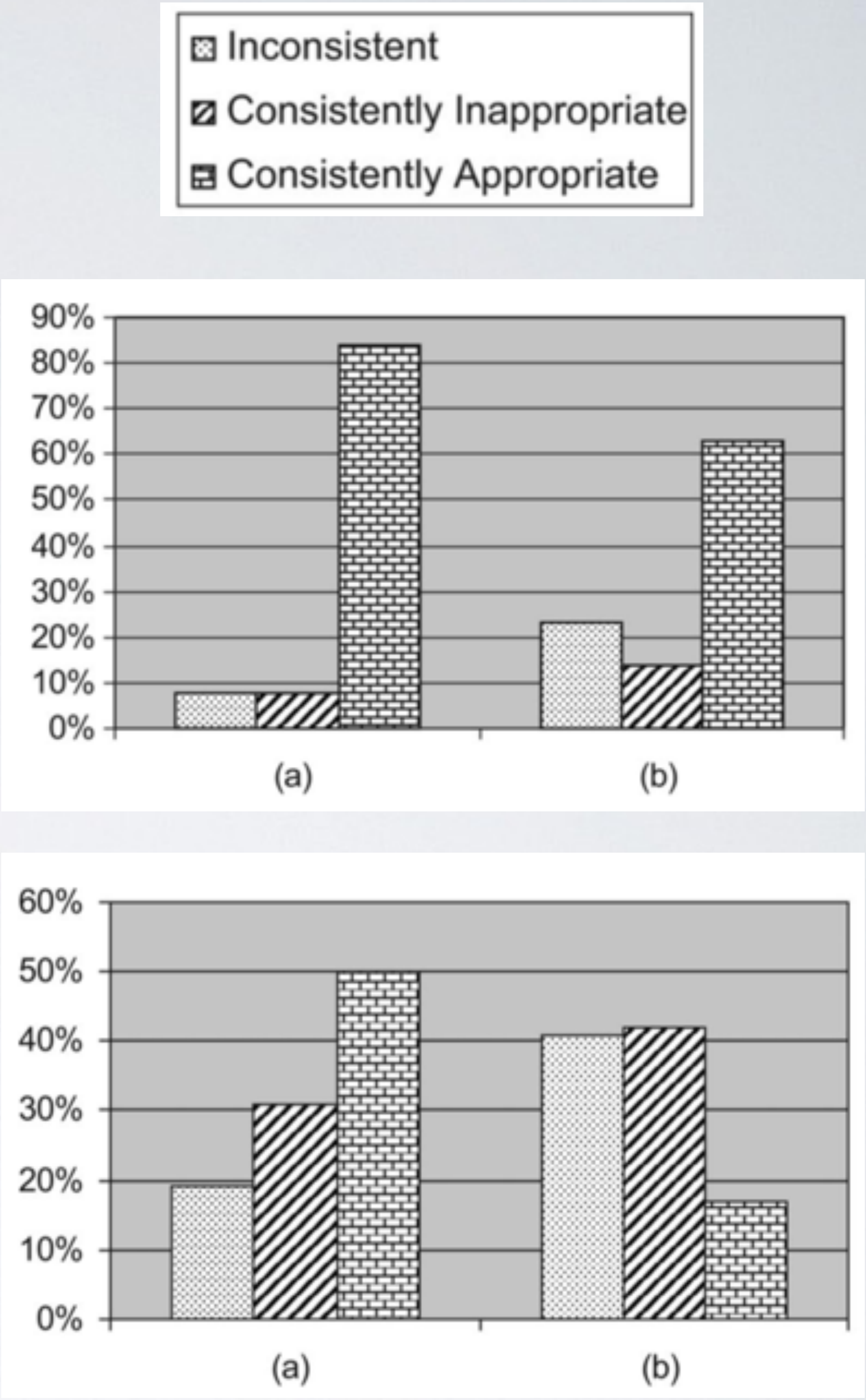
- Discussion
  - Significant difference between treatments (p = 0.0202)
  - It might take more time and practice to construct valid models
  - Some participants might be building simplified models at first
  - Some see they’re wrong but don’t know why
  - Reference is harder, requires more base knowledge
  - Tool might not be at students’ level

STUDY C

- Repeat motivation study to evaluate proposed teaching method
- 66 participants
  - from freshman Java course
  - near the end of the course
  - 22 participated in study A
  - 18 participated in study B
  - 14 participated in both
- Exact same test and conditions as motivational study

STUDY C

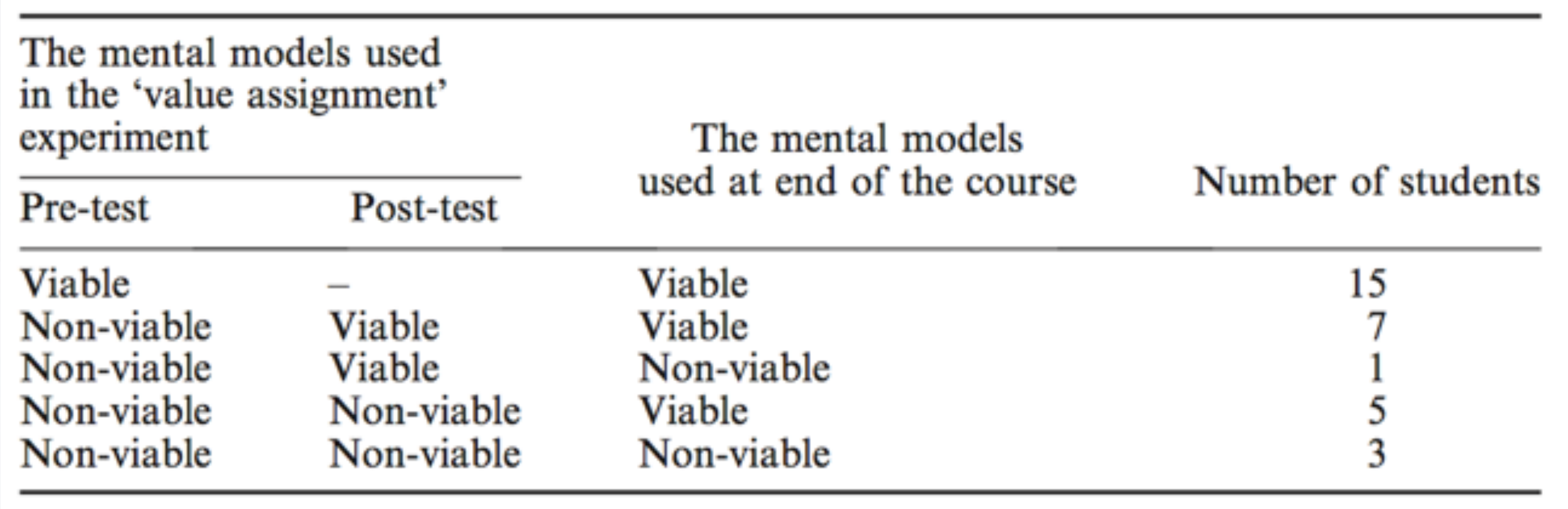
- Results:
  - 30 of 36 (from study A) used appropriate models for value assignment
    - significant (p = 0.0282)
  - 16 of 32 (from study B) used appropriate models for reference assignment
    - significant (p = 0.0002)



STUDY C

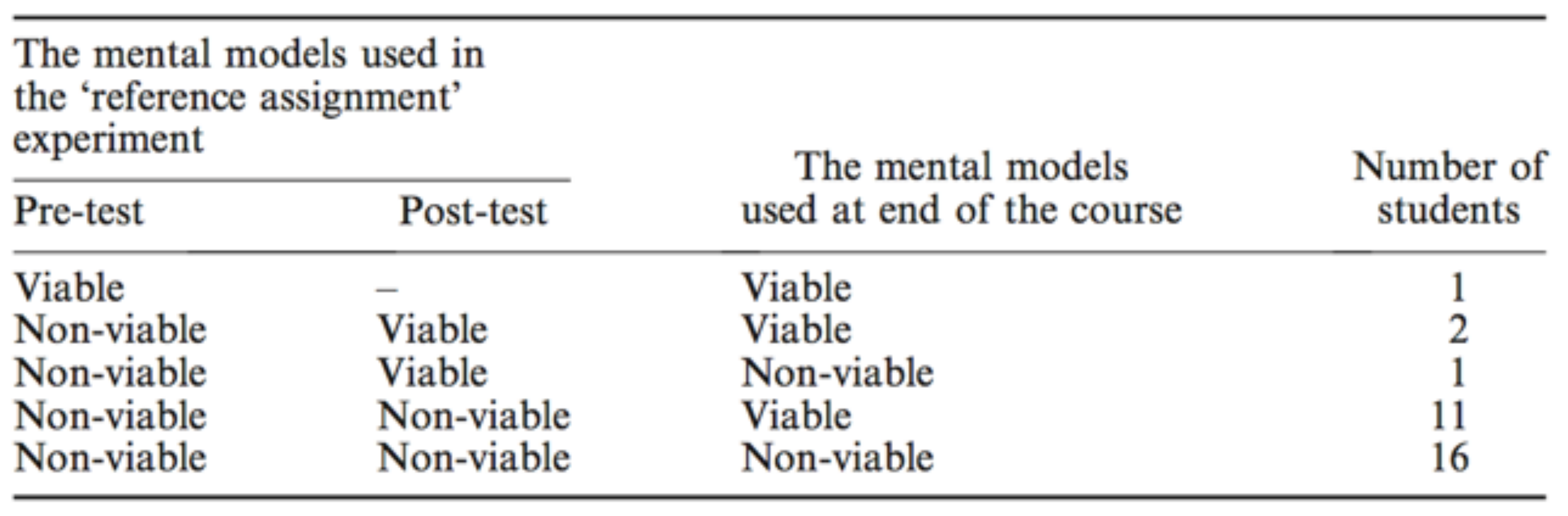
- Results:
  - Compared test results to those from Studies A and B

Value Assignment



The mental models used in the ‘value assignment’ experiment		The mental models used at end of the course	Number of students
Pre-test	Post-test		
Viable	–	Viable	15
Non-viable	Viable	Viable	7
Non-viable	Viable	Non-viable	1
Non-viable	Non-viable	Viable	5
Non-viable	Non-viable	Non-viable	3

Reference Assignment



The mental models used in the ‘reference assignment’ experiment		The mental models used at end of the course	Number of students
Pre-test	Post-test		
Viable	–	Viable	1
Non-viable	Viable	Viable	2
Non-viable	Viable	Non-viable	1
Non-viable	Non-viable	Viable	11
Non-viable	Non-viable	Non-viable	16

DISCUSSION

- Potential confounding factors
  - Some non-viable models may not have been challenged appropriately by the cognitive conflict portion
  - Interest in study participation might select students with higher drive, or encourage pressure to learn
- Conclusions
  - For straightforward concepts (assignment), cognitive conflict did not seem to add much
  - For harder concepts (reference), cognitive conflict had a more obvious impact
  - Analysis points to success for the proposed teaching model in terms of student understanding

DISCUSSION

- What are your thoughts on the cognitive conflict and constructivist model?

- Have you had experience with these concepts, either in class or otherwise?

- How would you utilize the proposed teaching model in your classrooms or field of study?

- Are there any areas that would not benefit from the proposed model?

FIN

Thank you for your attention and thoughts!