EPFL

CS-411

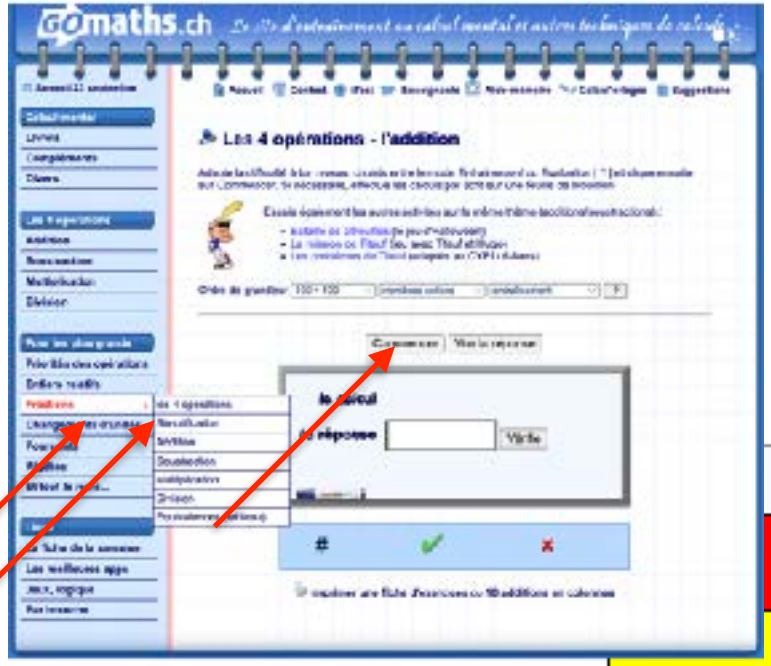
# Chapter 4: Discovery learning

Pierre Dillenbourg

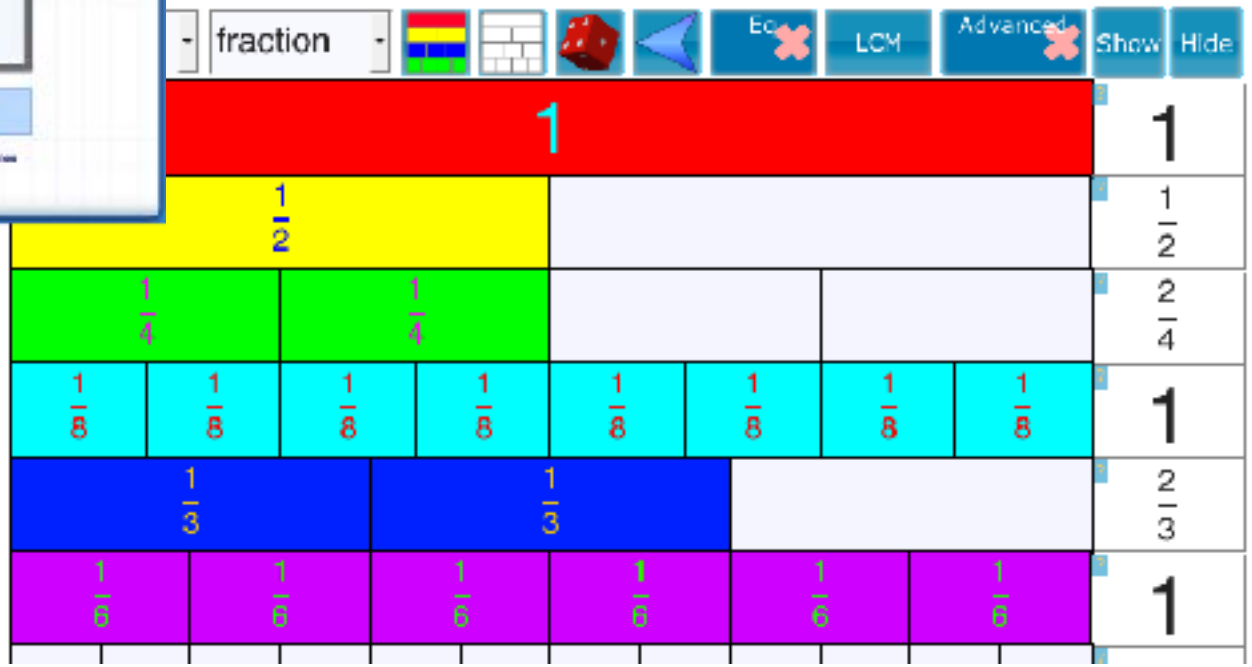
# How do people learn ?

- by exploration, trial and error
- by incremental mastery
- by verbal elaboration

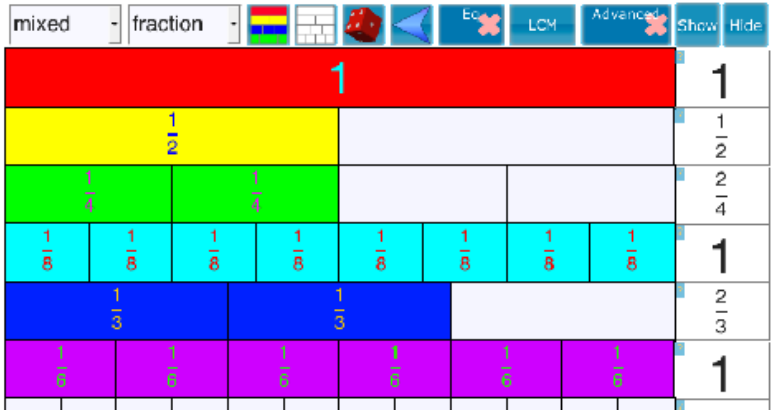
# Learning Fractions: Comparing 2 methods



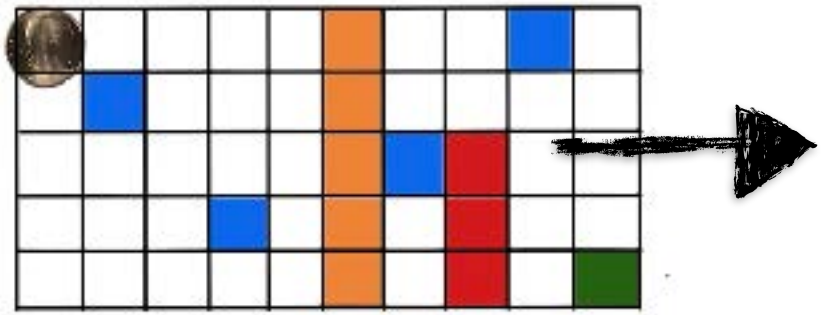

- https://gomaths.edu-vd.ch/cf_mix.php

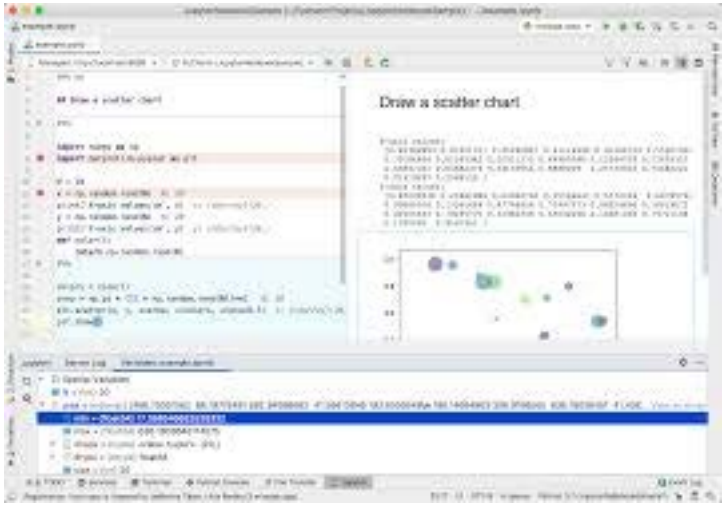



https://www.visnos.com/demos/fraction-wall

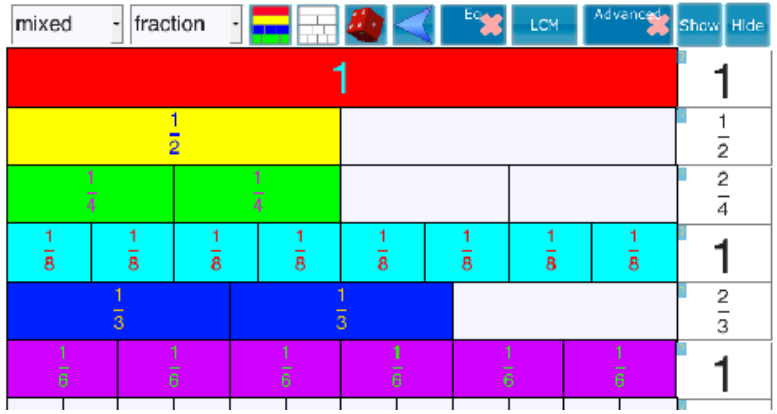

Inverse Reinforcement Learning

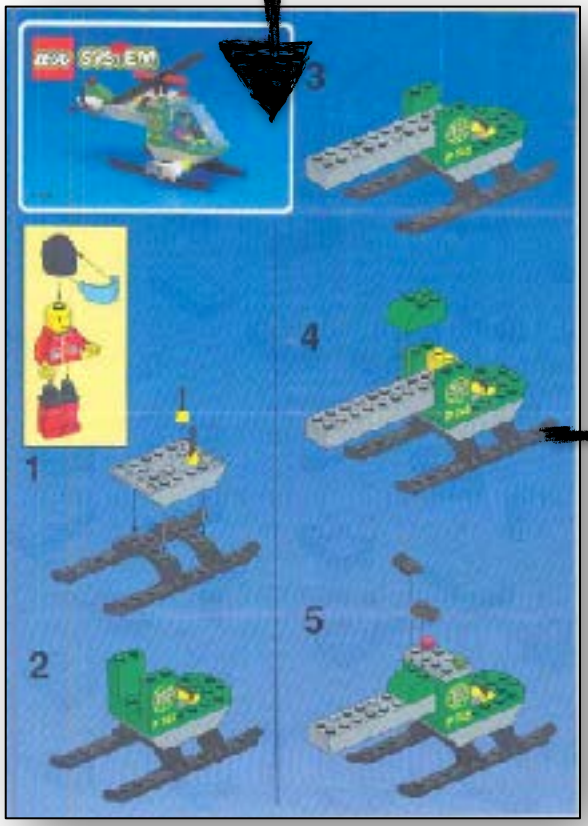





https://www.youtube.com/watch?v=h7uGyBcIeII


Simplification de fractions


mixed
fraction
LCM
Advanced
Show
Hide




https://upwardsleader.com/2016/10/24/how-to-lead-with-a-sandbox-culture/

# Curriculum ?

# Lesson A

A **splountz** is a triangle with 3 smaller shapes placed on different sides, one in the same color as the triangle and the two others in a different color.

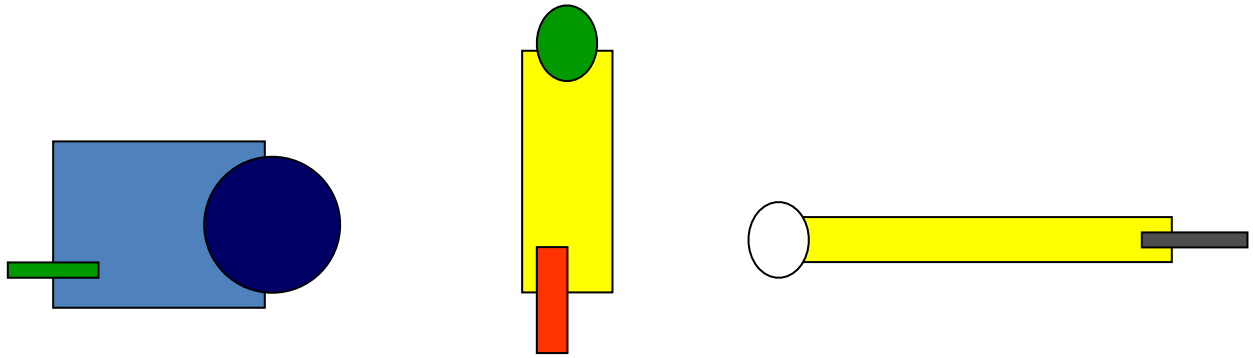
Is this a Splountz ?

○ Yes

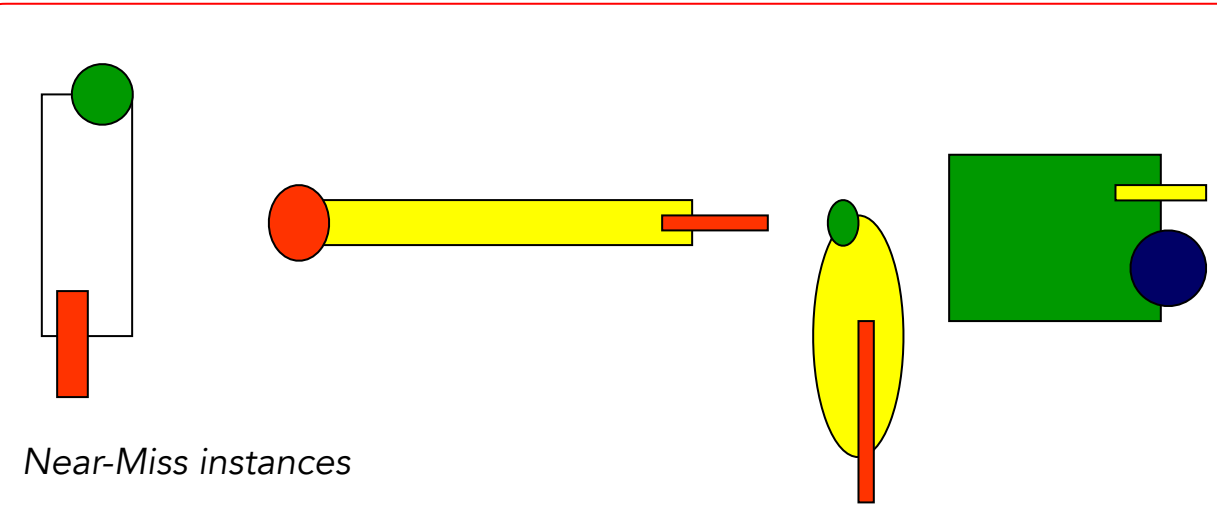
✔ No

# Lesson B

## WHAS IS A SPUC ?

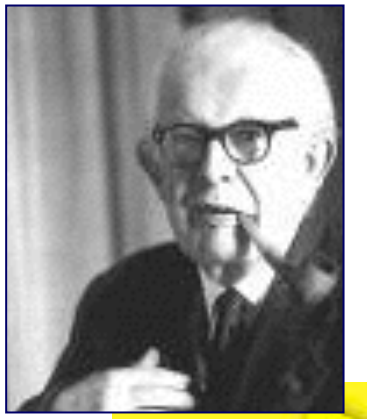


Positive instances



*Near-Miss instances*

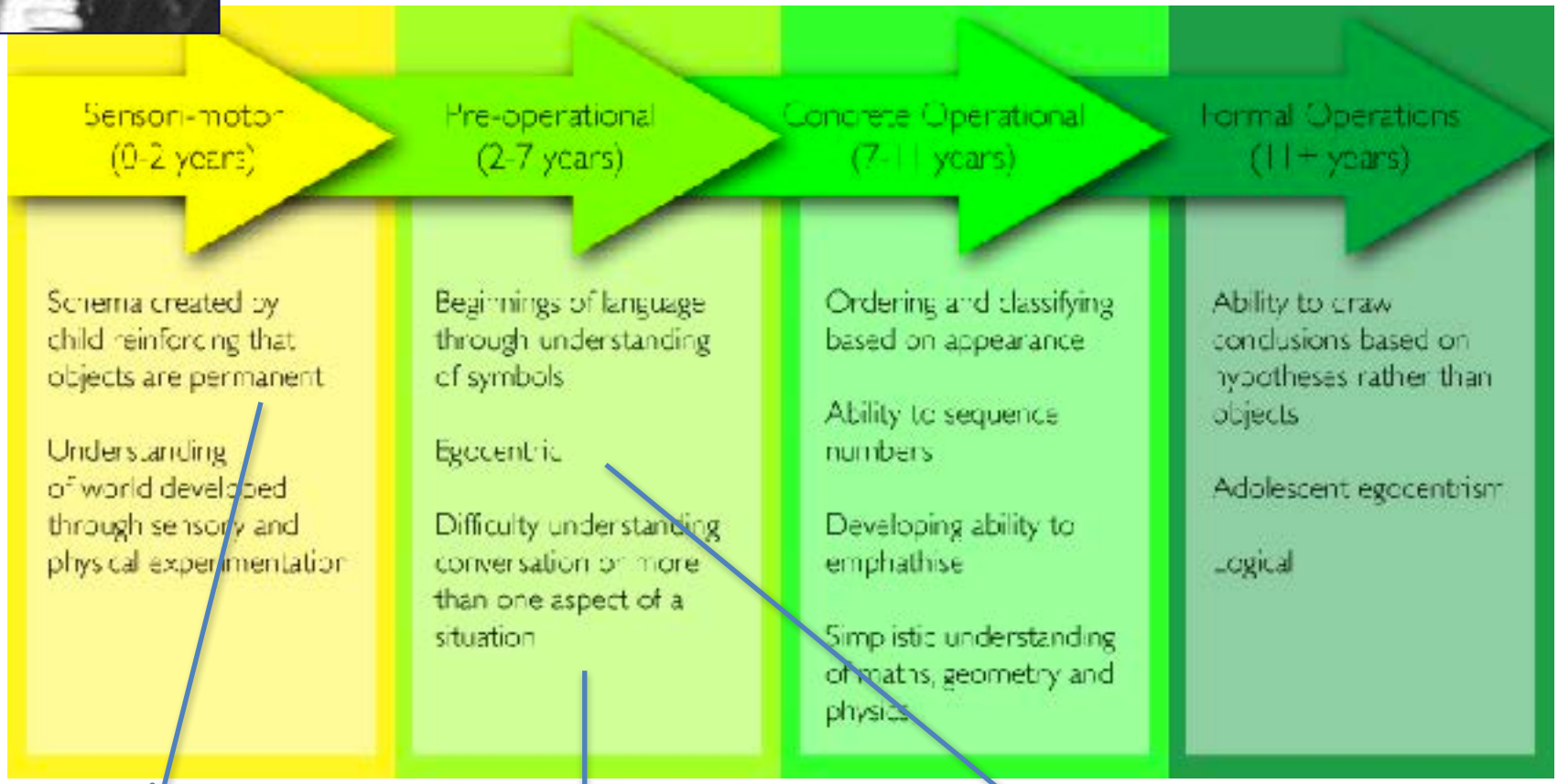
Negative instances



# Stages of cognitive development

**Constructivism**

Jean Piaget




https://www.papermasters.com/intellectual-growth.html

[Permanence of object]

[Conservation Task]

[PryramidTask]

# Assimilation and Accommodation

**How can this girl use her "dog" schema when encountering a cat?**

- She can **assimilate** the experience into her schema by referring to the cat as a "dog"

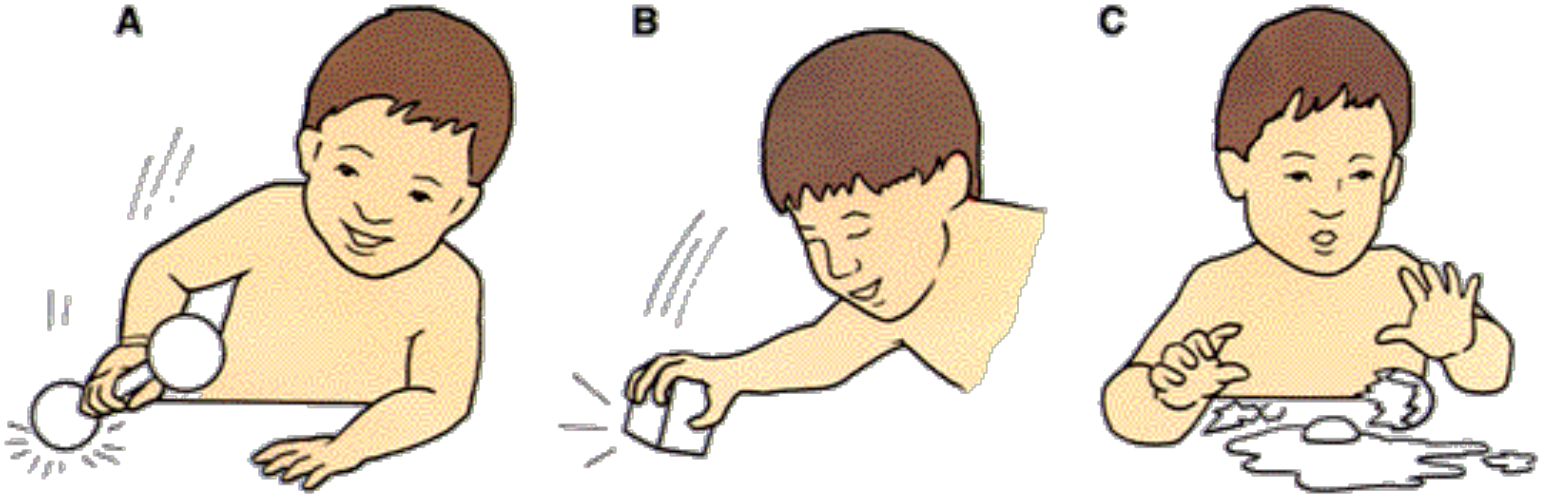
**or**

- she can **accommodate** her animal schema by separating the cat, and even different types of dogs, into separate schemas.



http://fr.slideshare.net/susanhansen1460/une-psy250-session-7-ist-2-years-language-piaget

http://www.enkivillage.com/assimilation.html

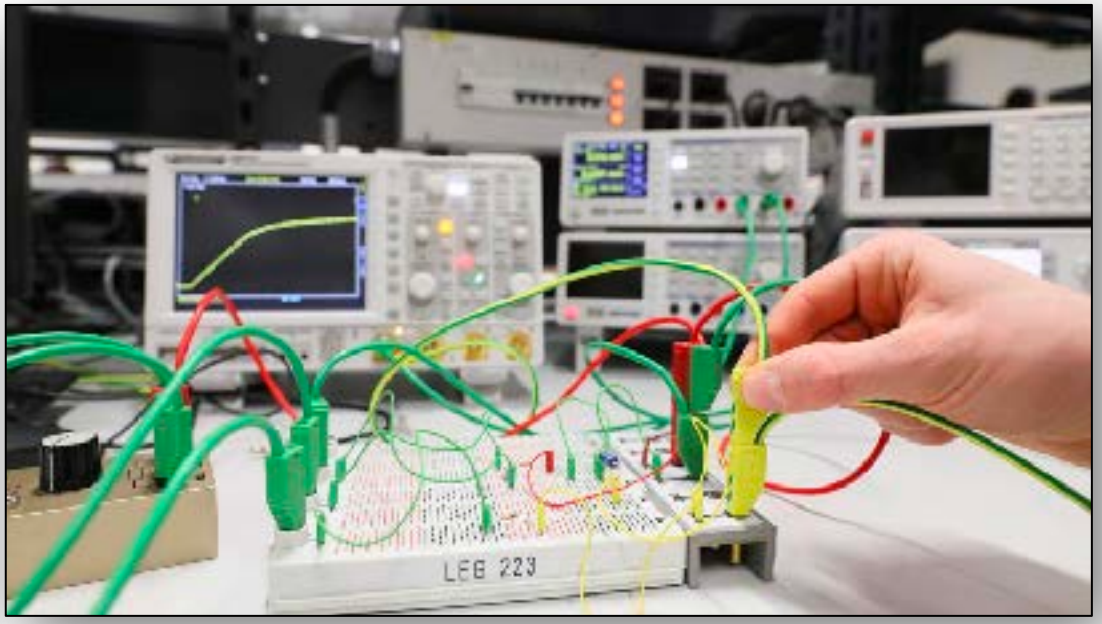



Piaget (1952) defined a schema as 'a cohesive, repeatable action sequence possessing component actions that are tightly interconnected and governed by a core meaning'. Basically, a scheme is the building block of intelligent behavior

# Cognitive Conflict
## as key learning mechanism

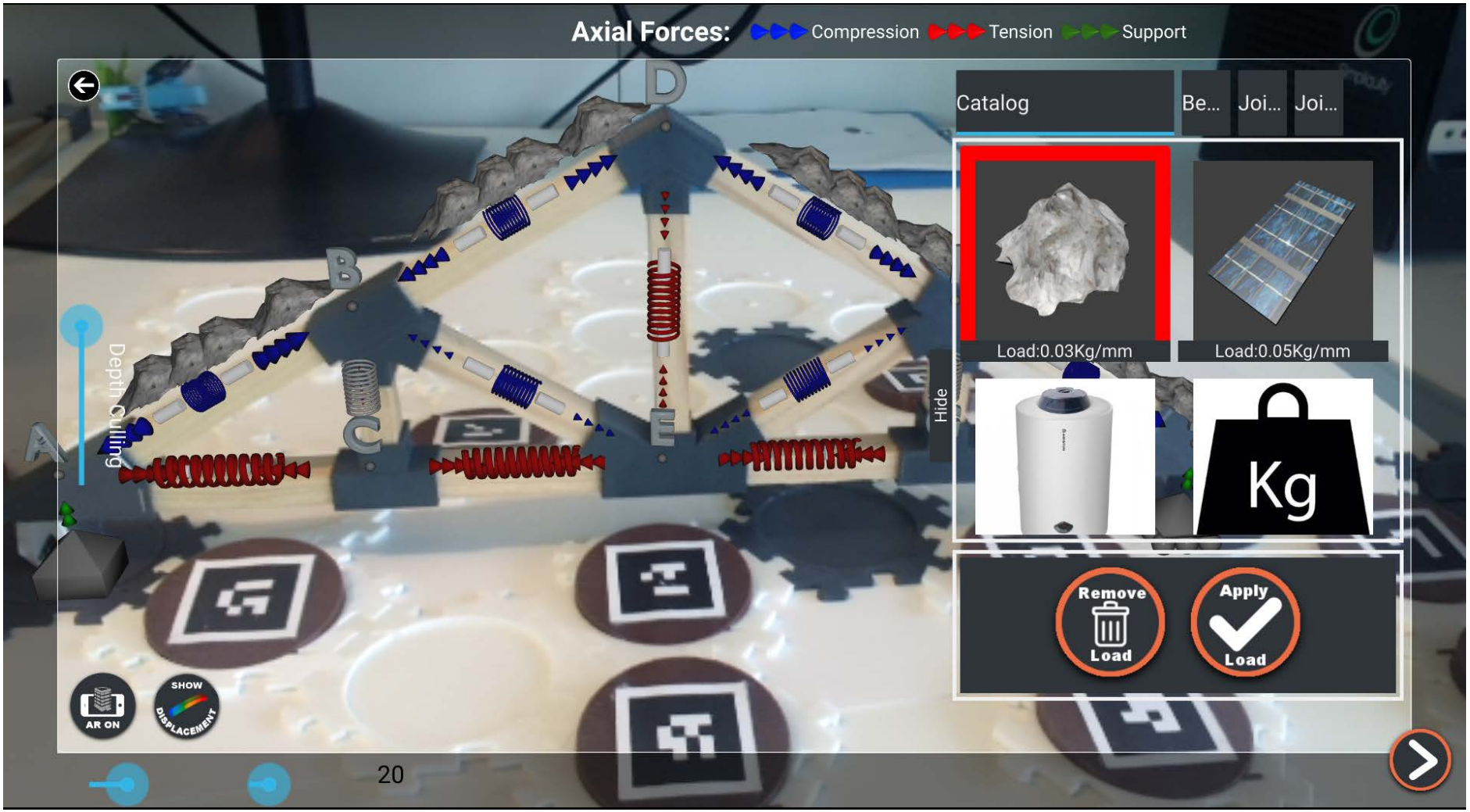
- Learning from experience
- Learning by doing
- Discovery learning


https://phet.colorado.edu/sims/html/gases-intro/latest/gases-intro_all.html?locale=fr




Discovery learning lab (The SPOT)

# Learning by (guided) Discovery ?




Discovery intuitive static principles (for carpenters) ?


STATICS

exploration

Learning by Discovery

Semi-Constructivism

There is a time for telling

No Over-expectation !

# "Productive Failure"

Who's the most consistent striker?

| Year | Mike Arwen | Dave Backhand | Ivan Right |
|---|---|---|---|
| 1988 | 14 | 13 | 13 |
| 1989 | 9 | 9 | 18 |
| 1990 | 14 | 16 | 15 |
| 1991 | 10 | 14 | 10 |
| 1992 | 15 | 10 | 16 |
| 1993 | 11 | 11 | 10 |
| 1994 | 15 | 13 | 17 |
| 1995 | 11 | 14 | 10 |
| 1996 | 16 | 15 | 12 |
| 1997 | 12 | 19 | 14 |
| 1998 | 16 | 14 | 19 |
| 1999 | 12 | 12 | 14 |
| 2000 | 17 | 15 | 18 |
| 2001 | 13 | 14 | 9 |
| 2002 | 17 | 17 | 10 |

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45-83.

Comparing regularity

Mike Arwen : Mean = $\frac{280}{20}$ = 14 goals / year

Mode = 14

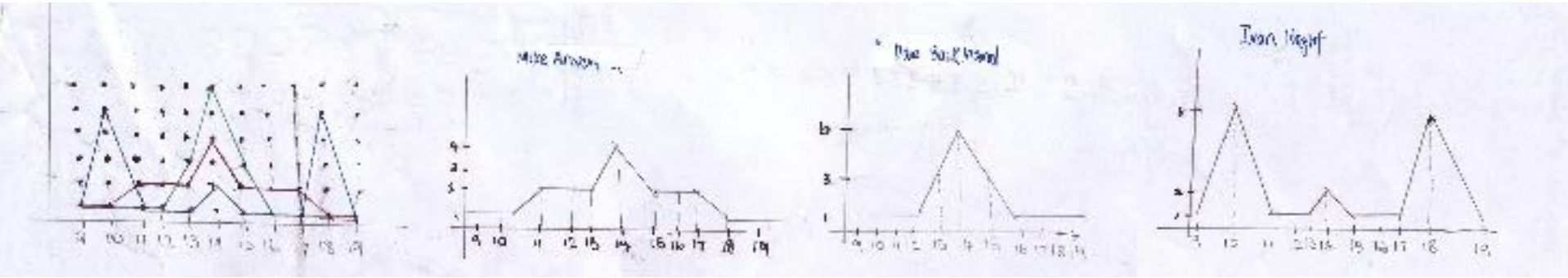
Dave Backhand : Mean = $\frac{280}{20}$ = 14 goals / year

Mode = 14

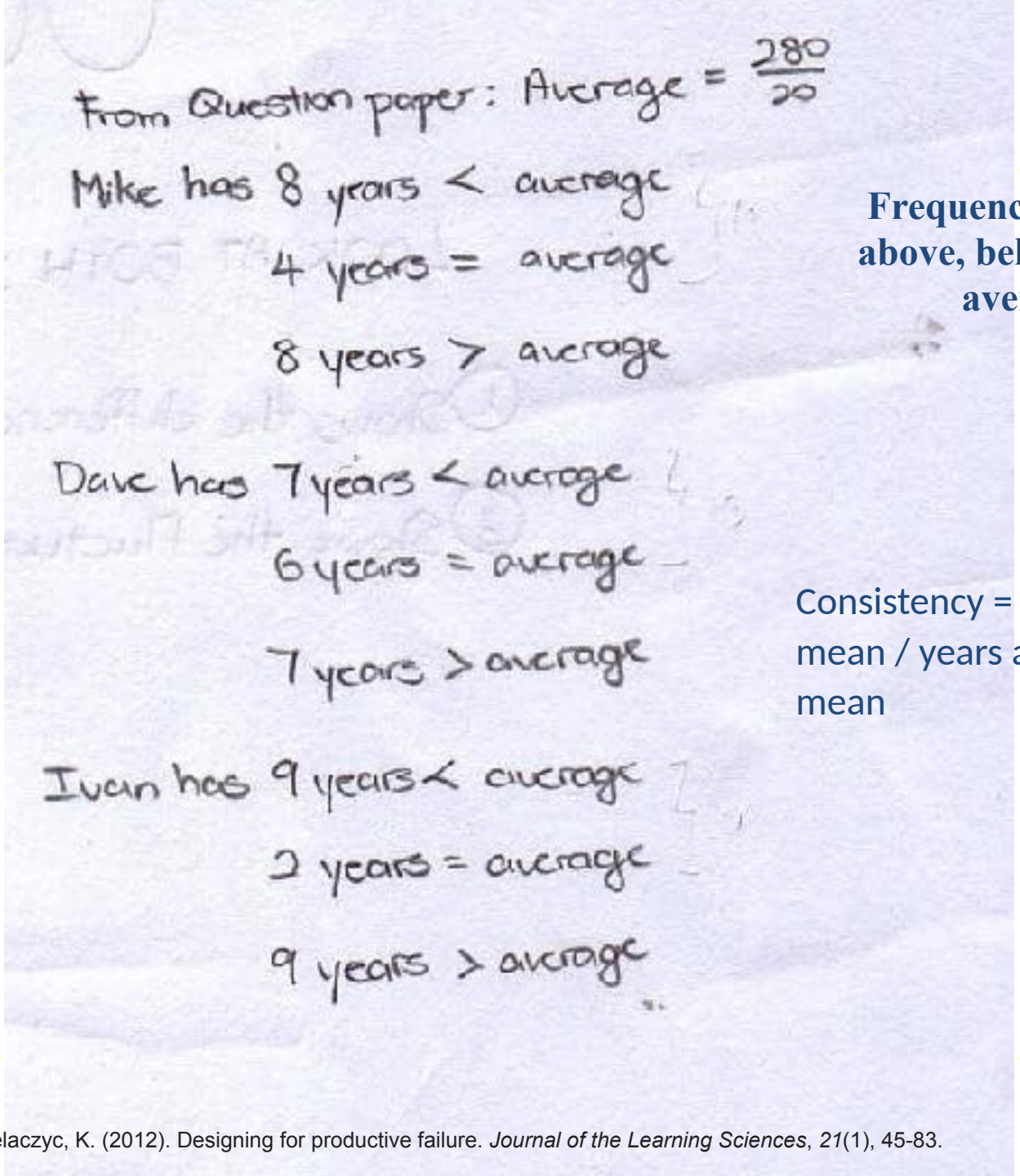
Ivan Right : Mean = $\frac{280}{20}$ = 14 goals / year

Mode = 18 and 10

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mike Arwen | 1 | 1 | 2 | 2 | 2 | 4 | 2 | 2 | 2 | 1 | 1 |
| Dave Backhand | 1 | 1 | 1 | 1 | 3 | 6 | 3 | 1 | 1 | 1 | 1 |
| Ivan Right | 1 | 5 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 5 | 1 |




9 10 11 11 12 12 13 13 14 14 14 14 15 15 16 16 17 17 18 19

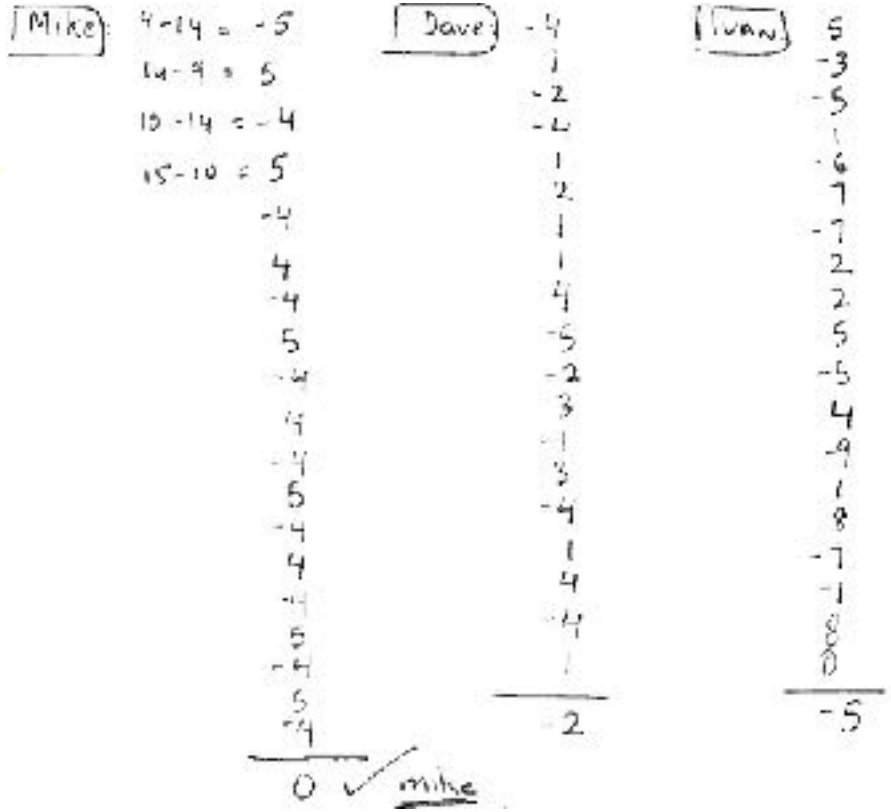


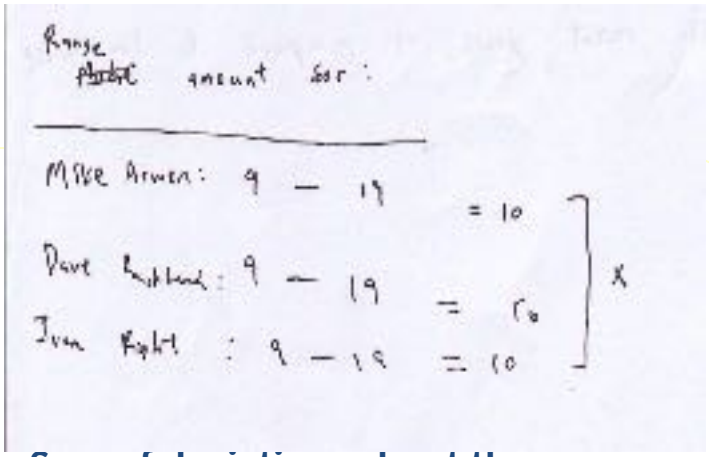

**Frequency of years above, below, and at average**

Consistency = years at the mean / years away from the mean

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45-83.

## Sum of year-on-year deviation




## Sum of deviations about the mean

| Year | Avg | M-A | S-B | T-E | x | | |
|---|---|---|---|---|---|---|---|
| 1989 | 14 | 14 | 13 | 13 | 0 | -1 | -1 |
| 1990 | 14 | 9 | 9 | 18 | 5 | -5 | 4 |
| 1991 | 14 | 14 | 16 | 15 | 0 | +2 | +1 |
| 1992 | 14 | 10 | 14 | 10 | -4 | 0 | -4 |
| 1993 | 14 | 15 | 10 | 16 | +1 | -4 | +2 |
| 1994 | 14 | 11 | 11 | 10 | -3 | -3 | -4 |
| 1995 | 14 | 15 | 13 | 17 | +1 | -1 | +3 |
| 1996 | 14 | 11 | 14 | 10 | -3 | 0 | -4 |
| 1997 | 14 | 16 | 15 | 12 | +2 | +1 | -2 |
| 1998 | 14 | 12 | 14 | 14 | -2 | +5 | 0 |
| 1999 | 14 | 16 | 14 | 10 | +2 | 0 | -3 |
| 2000 | 14 | 12 | 12 | 12 | -2 | -2 | 0 |
| 2001 | 14 | 17 | 15 | 18 | +3 | +1 | +4 |
| 2002 | 14 | 13 | 14 | 9 | -1 | 0 | -5 |
| 2003 | 14 | 14 | 17 | 15 | +3 | +3 | -1 |
| 2004 | 14 | 13 | 13 | 18 | -1 | -1 | +4 |
| 2005 | 14 | 14 | 14 | 11 | 0 | 0 | -3 |
| 2006 | 14 | 14 | 18 | 15 | 0 | +4 | -4 |
| 2007 | 14 | 14 | 14 | 18 | +3 | 0 | +3 |
| | | | | | 0 | +1 | -1 |
| | | | | | Total: | | |

## Average of year-on-year absolute deviation

MIKE = 5+5+4+5+4+4+4+5+1+1+4+1+4+5+4+4+4+1+5+4+5+4 / 20 − 1

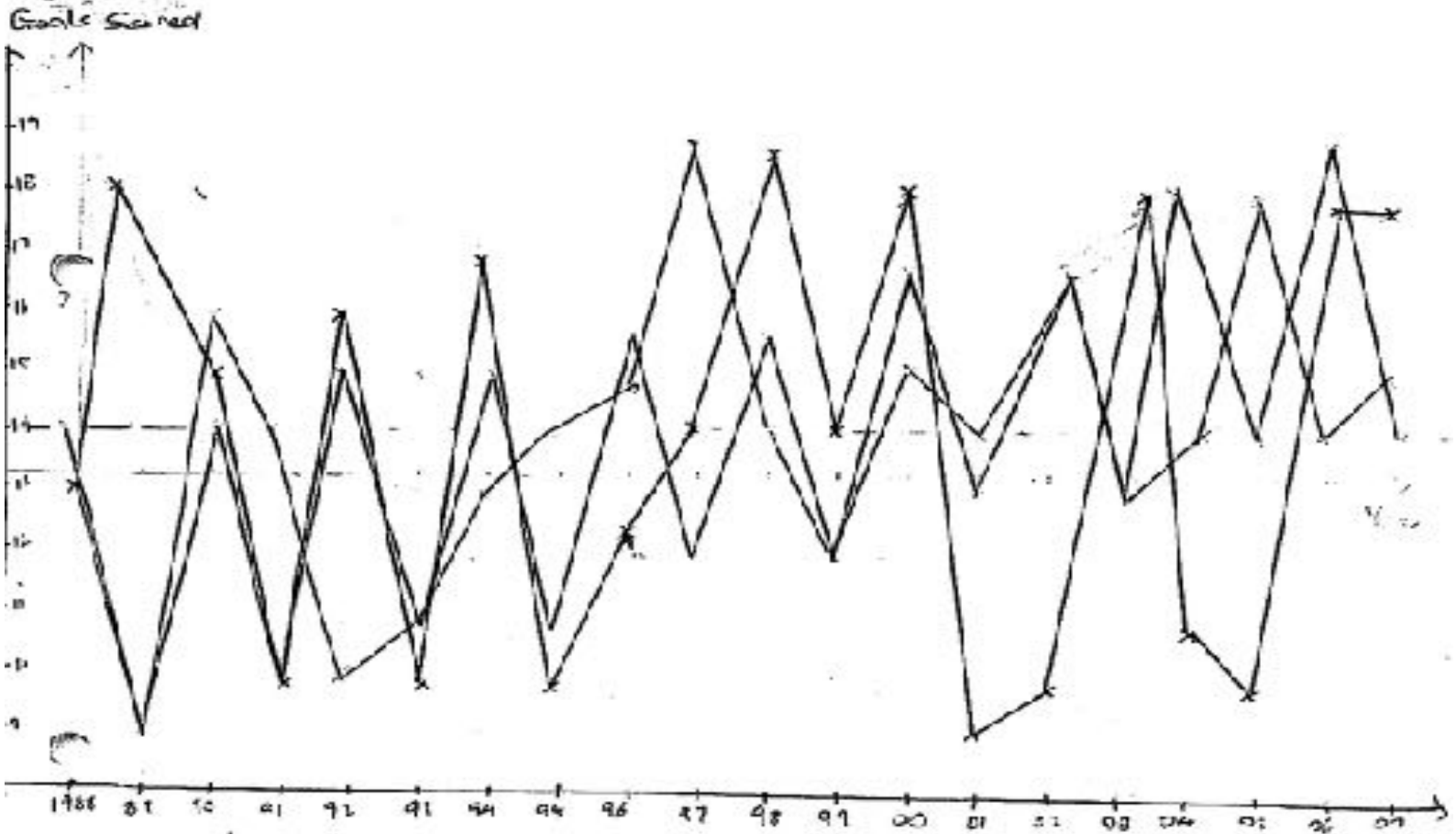
= 84/19 = 4.26

DAVE = 4+7+2+4+1+2+1+1+4+5+2+3+1+3+1+1+4+4+1 / 19

= 54/19 = 2.84 DAVE is more consistent

IVAN = 5+3+5+1+6+9+7+2+2+5+5+4+9+1+8+7+1+8+5 / 19

= 4.84




Idea 3 Measure Graph Length

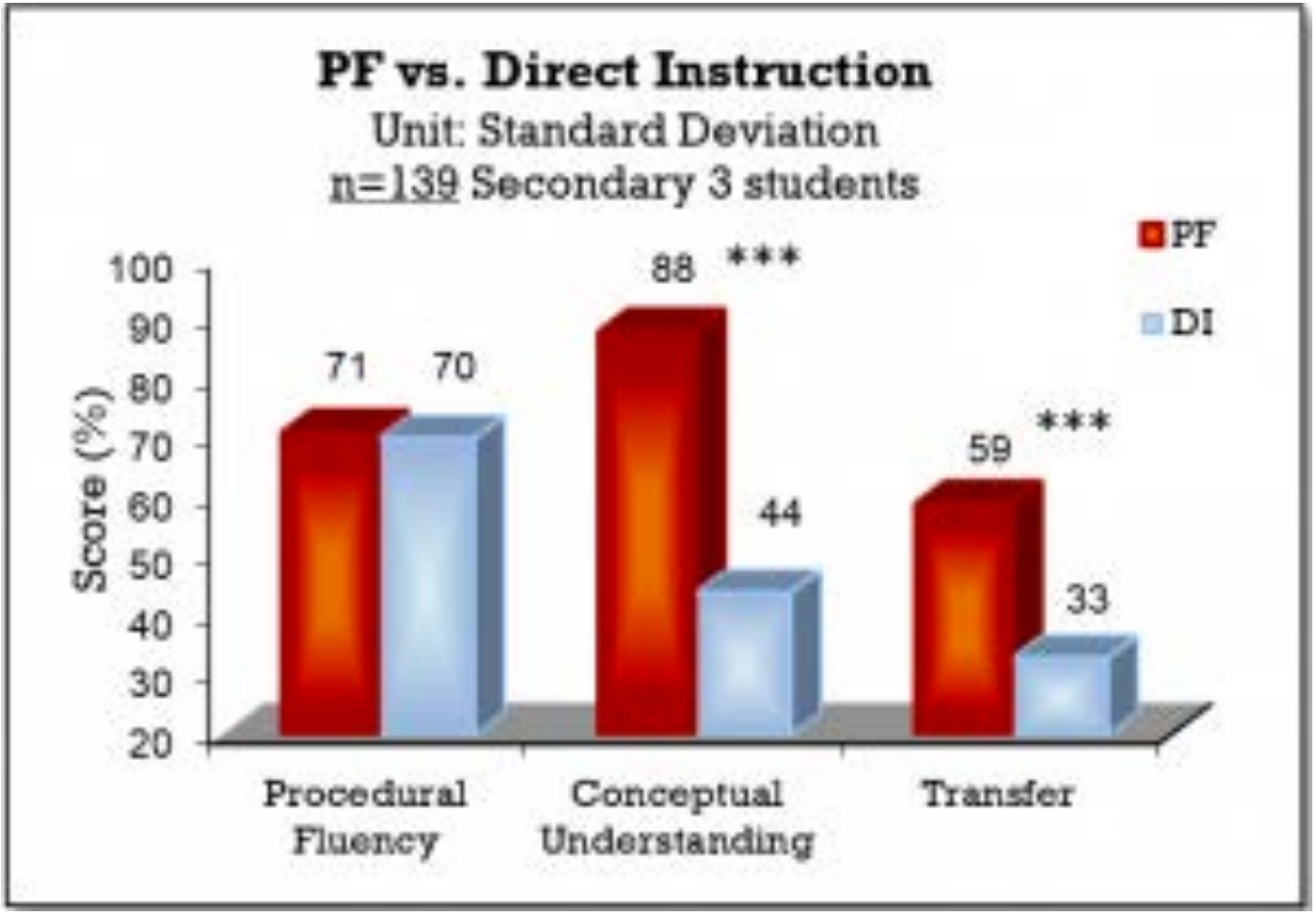
MA $\sqrt{26}+\sqrt{56}+\sqrt{17}+\sqrt{26}+\sqrt{17}+\sqrt{17}+\sqrt{17}+\sqrt{26}+\sqrt{10}+\sqrt{17}+\sqrt{17}+\sqrt{26}+\sqrt{17}+\sqrt{17}+\sqrt{17}+\sqrt{26}+\sqrt{17}+\sqrt{26}+\sqrt{41} = 83.26$

DB $\sqrt{17}+\sqrt{53}+\sqrt{5}+\sqrt{17}+\sqrt{5}+\sqrt{5}+\sqrt{26}+\sqrt{2}+\sqrt{17}+\sqrt{26}+\sqrt{2}+\sqrt{10}+\sqrt{2}+\sqrt{5}+\sqrt{10}+\sqrt{2}+\sqrt{17}+\sqrt{17}+\sqrt{2} = 56.49$

IR $\sqrt{26}+\sqrt{10}+\sqrt{25}+\sqrt{17}+\sqrt{17}+\sqrt{53}+\sqrt{53}+\sqrt{5}+\sqrt{5}+\sqrt{2}+\sqrt{26}+\sqrt{17}+\sqrt{82}+\sqrt{26}+\sqrt{65}+\sqrt{53}+\sqrt{2}+\sqrt{65}+1 = 94.54$

∴ Dave Backhard is the most consistent player as he has the shortest "stretched-out" graph, staying consistency over time.

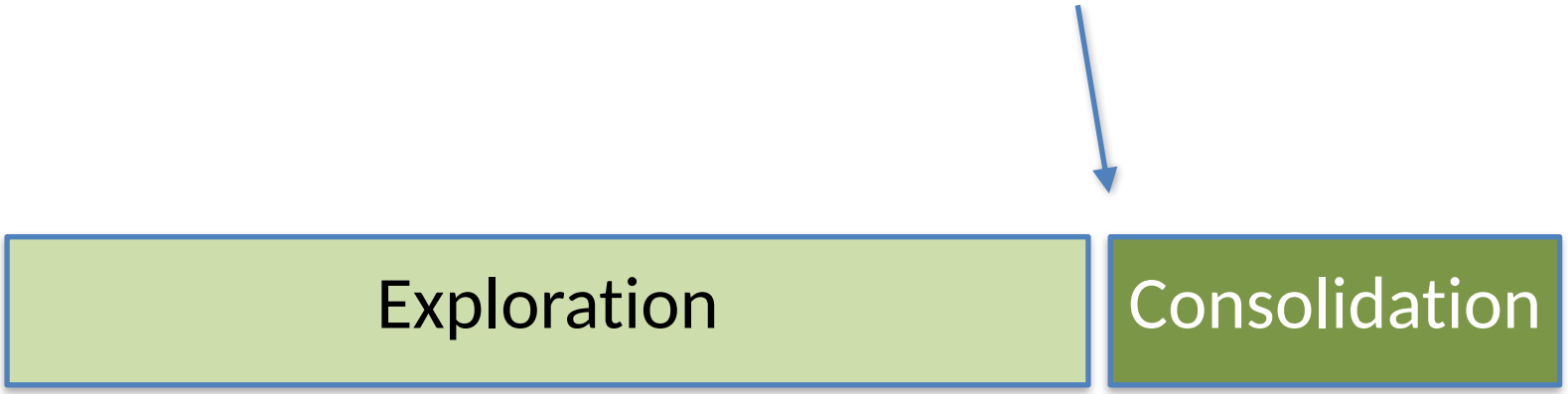
Azaac Aitken 3



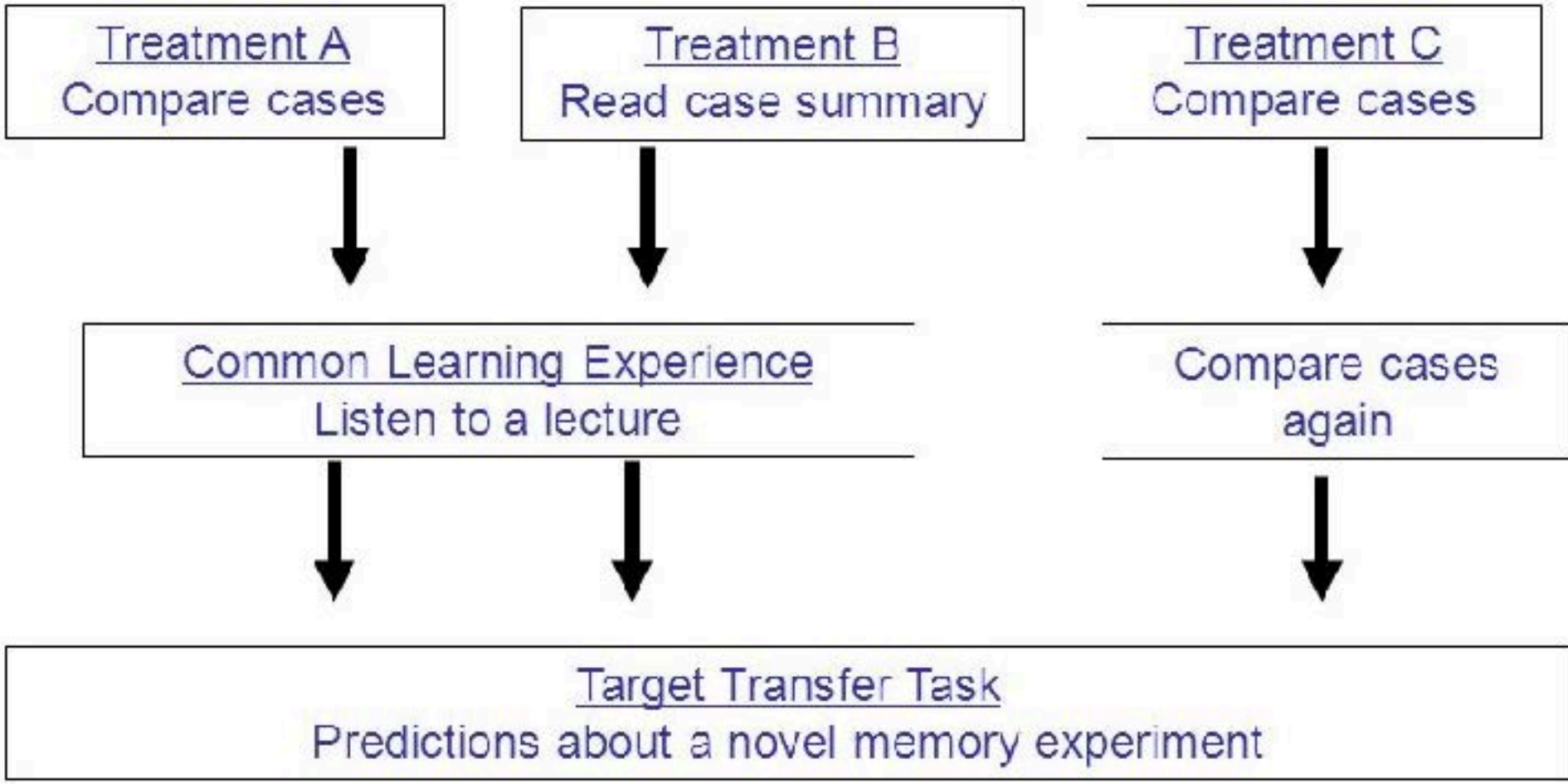

# Constructivism ≠ Teacherless

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45-83.

There is a time for telling



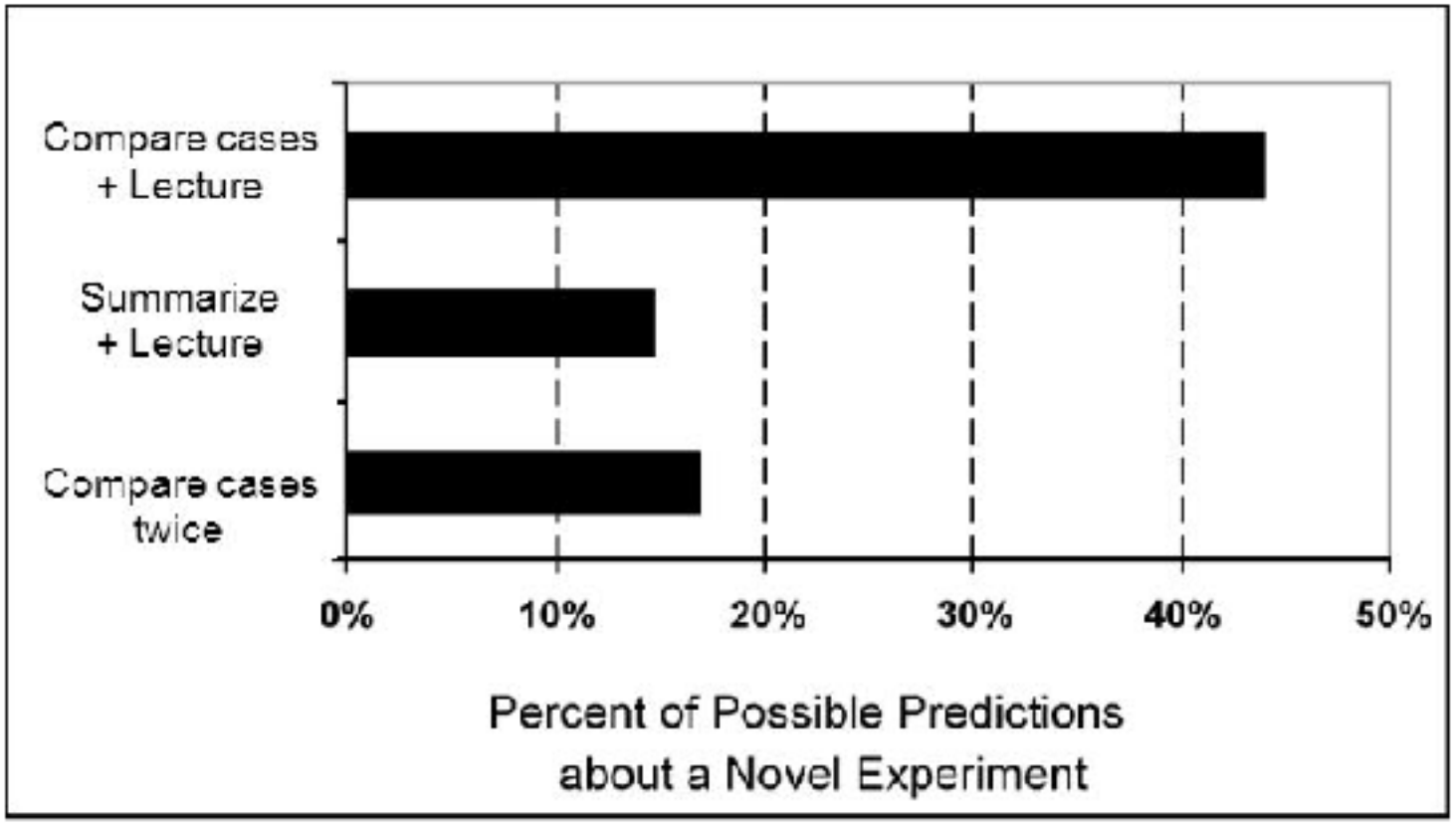
# « Contrasting Cases »



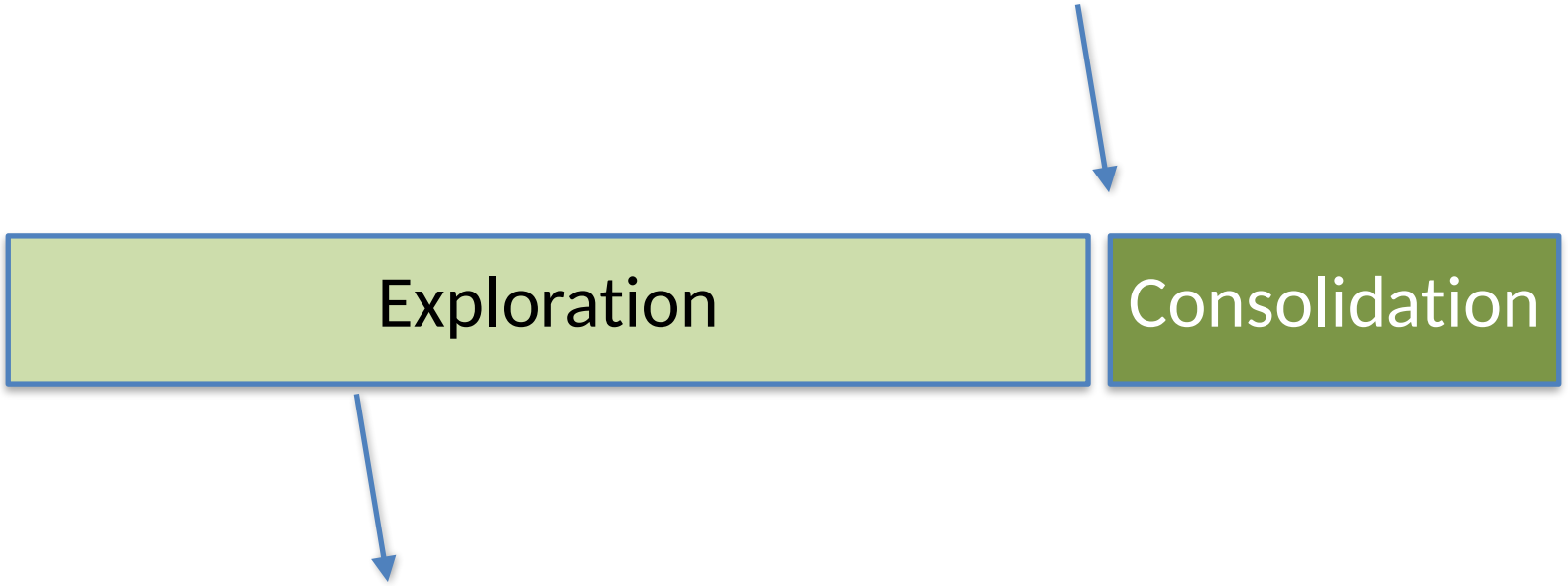

Lucinda Kelly

Daniel L. Schwartz & John D. Bransford (1998) A Time For Telling, Cognition and Instruction, 16:4, 475-5223, DOI: 10.1207/s1532690xci1604_4

# « Contrasting Cases »



There is a time for telling




How to guide learners ?

Don’t imitate Monthy Pithon

-

Exploration | Consolidation

1. **Carefully design the data set**
2. Comparisons, playing with differences
3. Conflict: trapping predictions
4. Advance organizers (metaphors,…)
5. Pushing reflection

| Year | Mike Arwen | Dave Backhand | Ivan Right |
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| 1988 | 14 | 13 | 13 |
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Exploration

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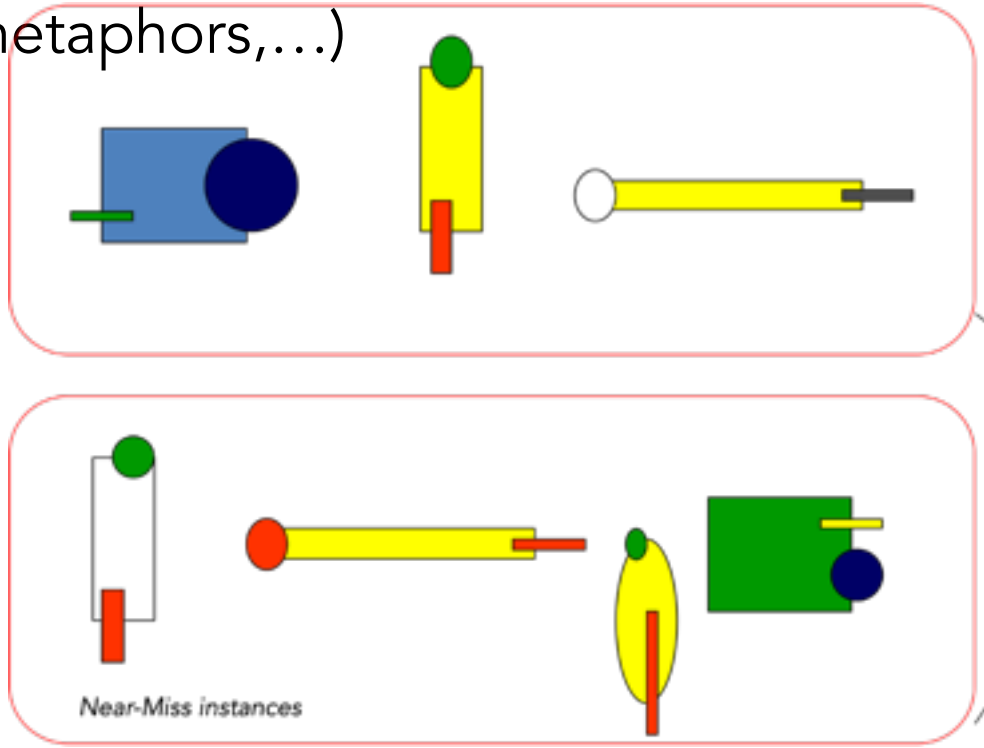


**Gloria and Tim were asked to solve $5(x + 3) = 20$.**

**Gloria's "distribute first" way**

$5(x + 3) = 20$

$5x + 15 = 20$

$5x + 15 = 20$

$-15 \quad -15$

$\frac{5x}{5} = \frac{5}{5}$

$x = 1$

*First I distributed.*

*Then I subtracted on both sides.*

*I divided by 5.*

*Here is my answer.*

**Tim's "divide first" way**

$5(x + 3) = 20$

$\frac{5(x + 3)}{5} = \frac{20}{5}$

$x + 3 = 4$

$-3 \quad -3$

$x = 1$

*First I divided by 5.*

*Then I subtracted from both sides.*

*Here is my answer.*

How did Gloria and Tim find the solution to the equation?

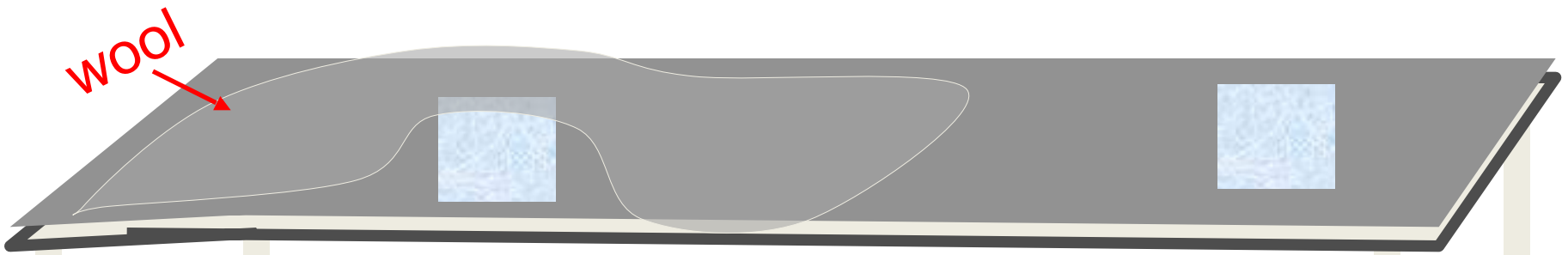
Which method is better? What are some important differences between Gloria's "distribute first" method and Tim's "divide first" method?

Exploration

Consolidation

1. Carefully design the data set
2. Comparisons, playing with differences
3. **Conflict: trapping predictions**
4. Advance organizers (metaphors,…)
5. Pushing reflection

# Trapping misconceptions



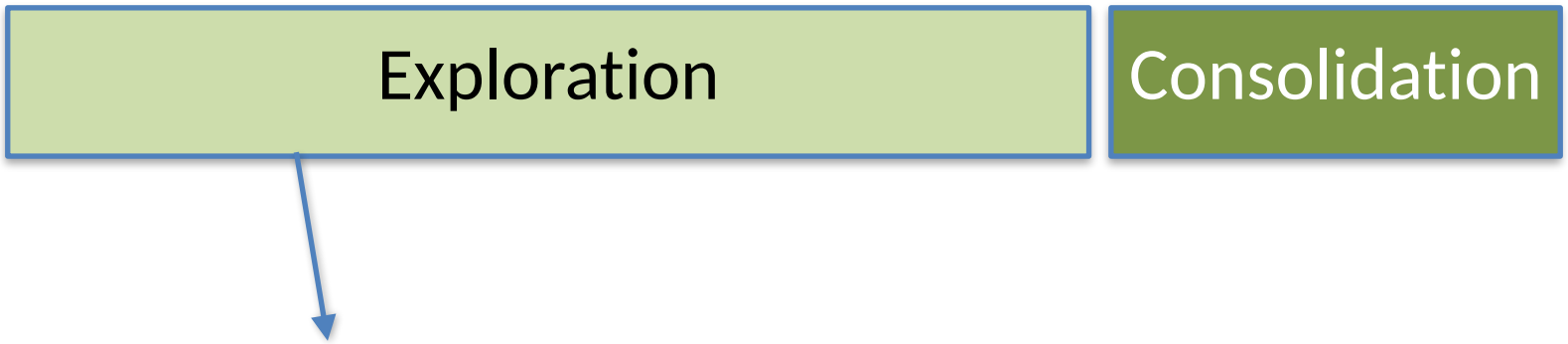

2 ice cubes at midnight, t = 20 C

Which ice cube will melt faster ?

Exploration

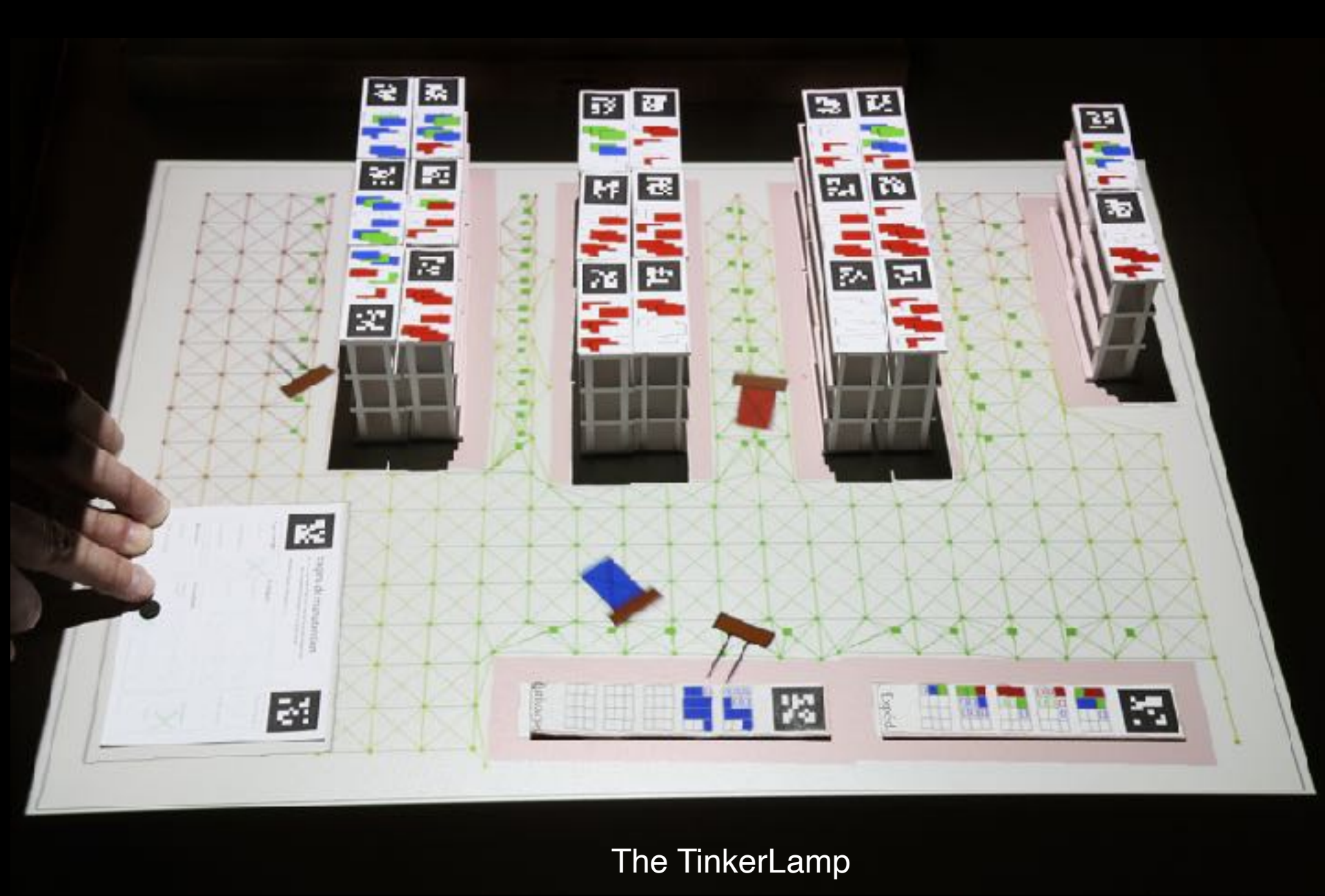
Consolidation

1. Carefully design the data set
2. Comparisons, playing with differences
3. Conflict: trapping predictions
4. **Advance organizers (metaphors,…)**
5. Pushing reflection




1. Carefully design the data set
2. Comparisons, playing with differences
3. Conflict: trapping predictions
4. Advance organizers (metaphors,…)
5. **Pushing reflection**

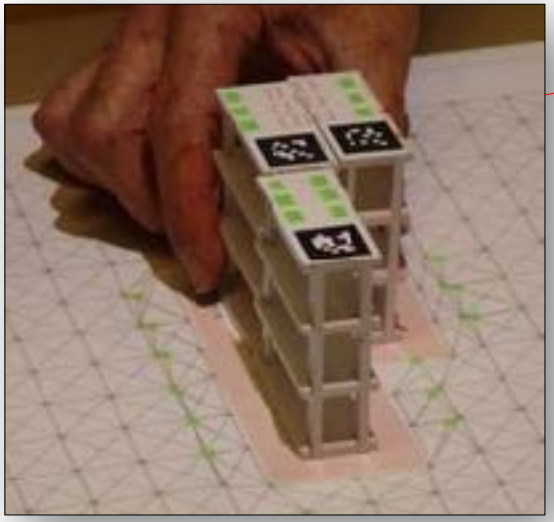

Apprentissage

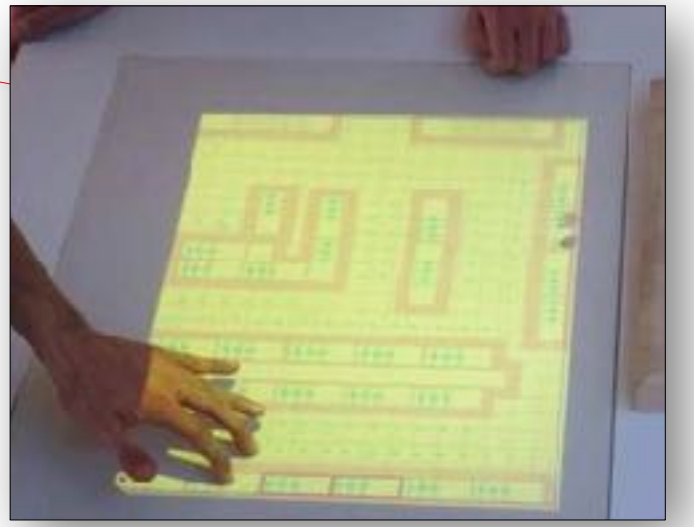


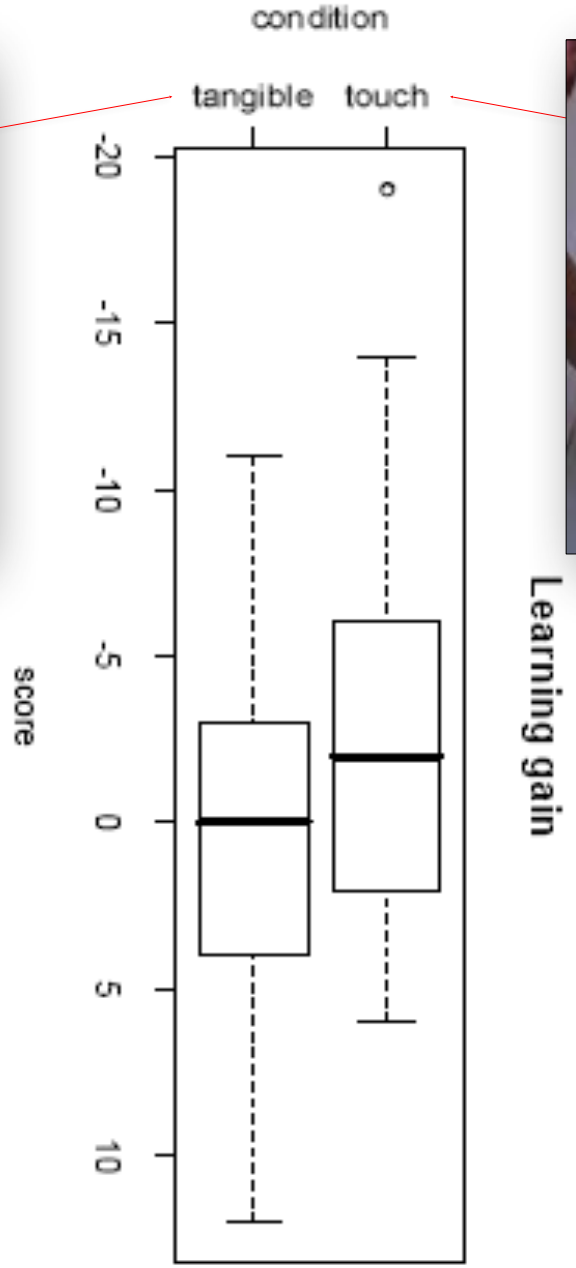
The TinkerLamp

*Guillaume Zufferey, Patrick Jermann*


Simpliquity

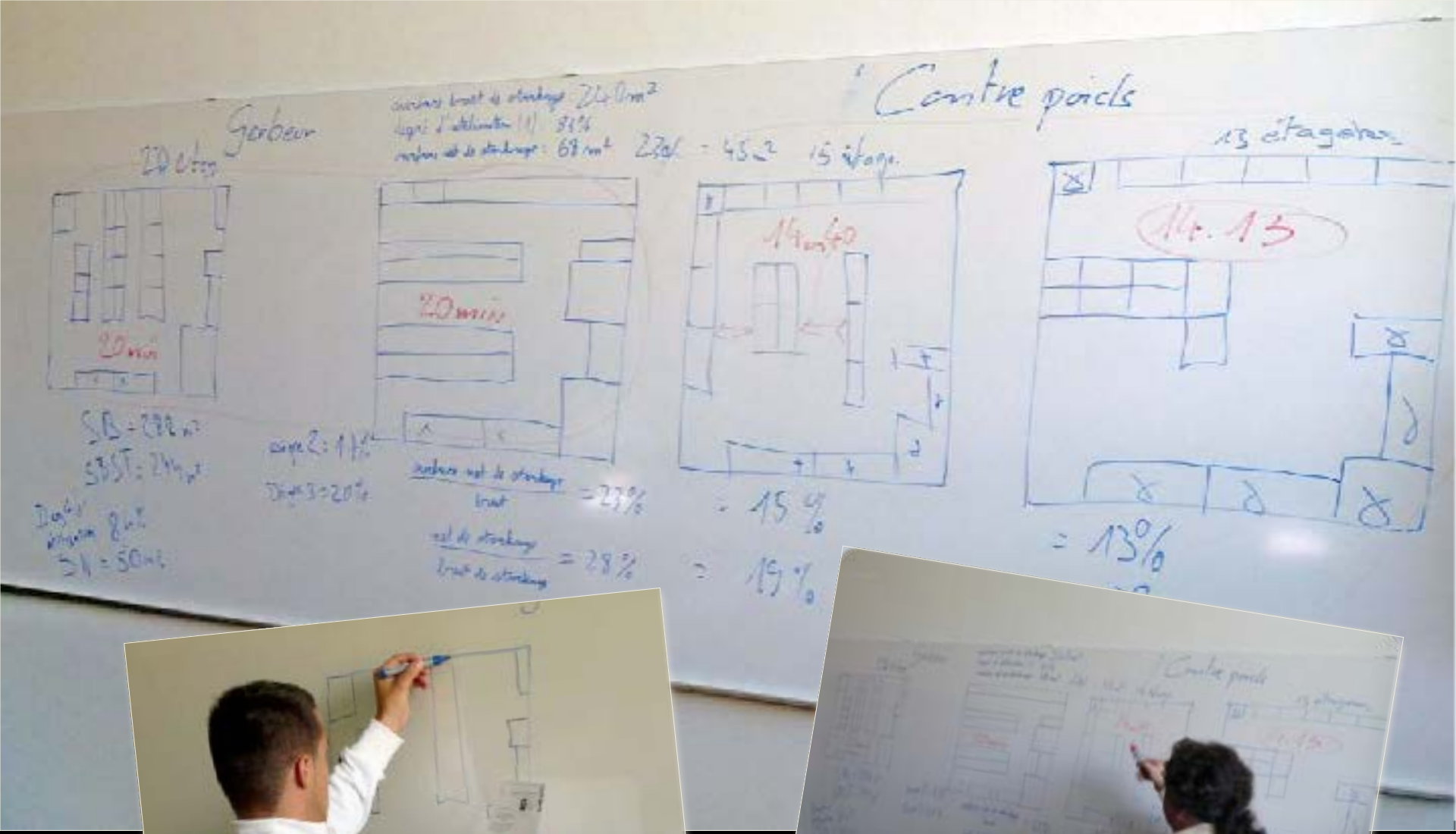




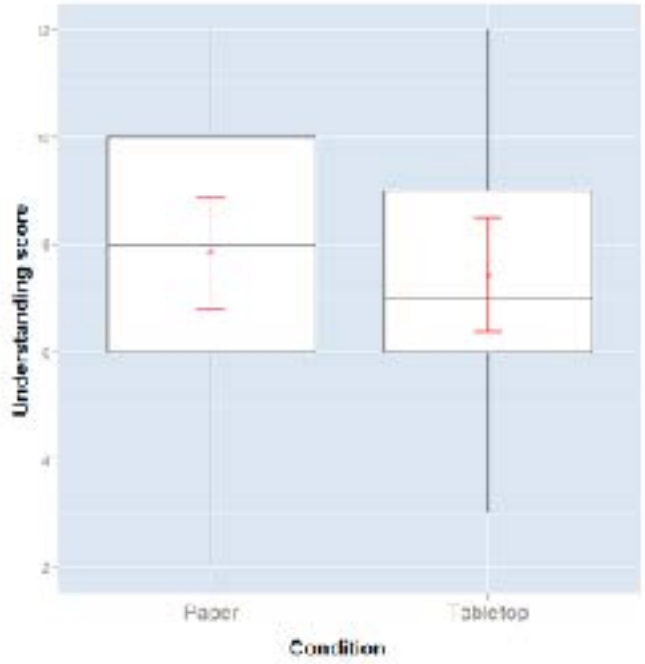



Learning gain

$F(1,37) = 6.68,\ p < .05$

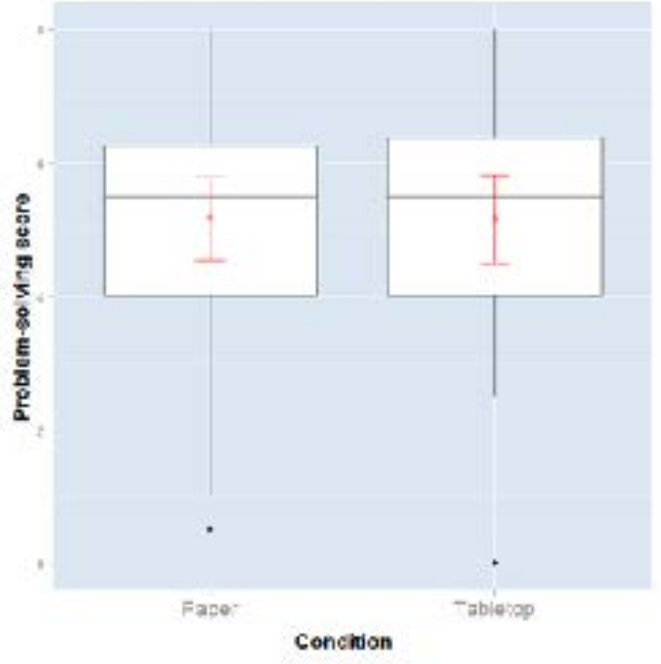

Gerbeur
Contre poids
20 min
20 min
11 min
11. 13

No sign. effect in understanding



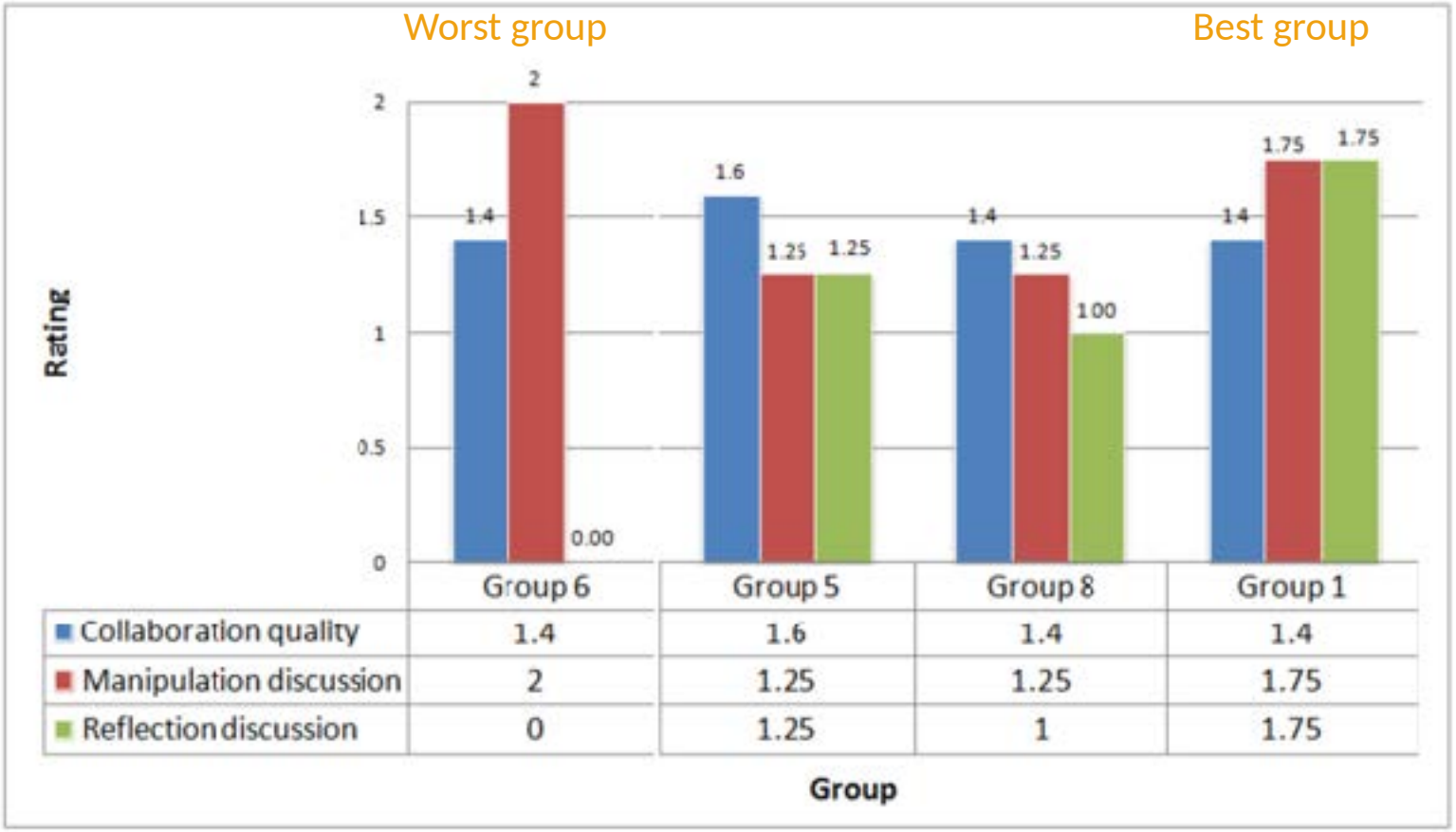

mean = 7.84 vs. mean = 7.43
F(1,14) = .25; p > .05

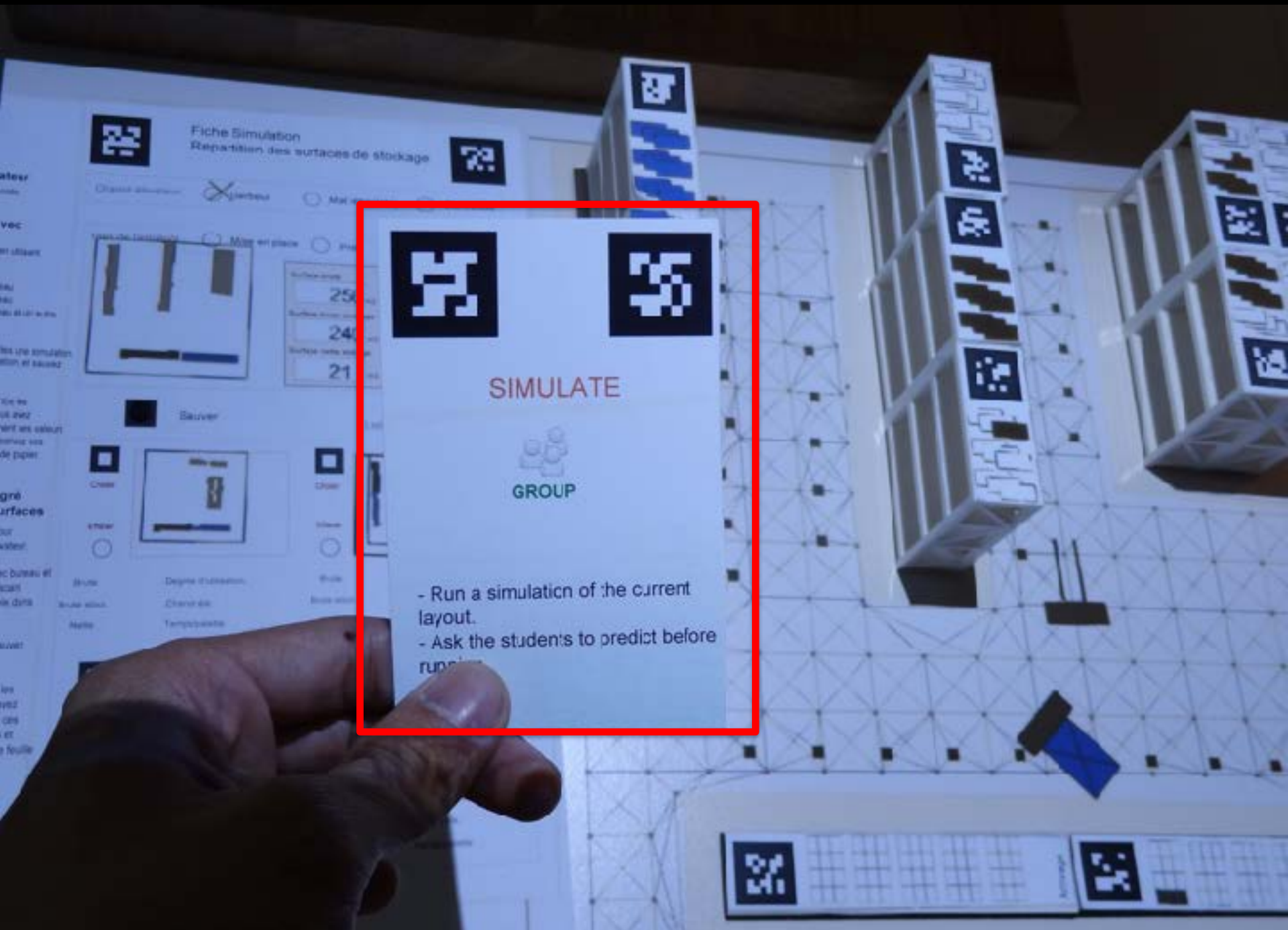
No sign. effect in problem-solving

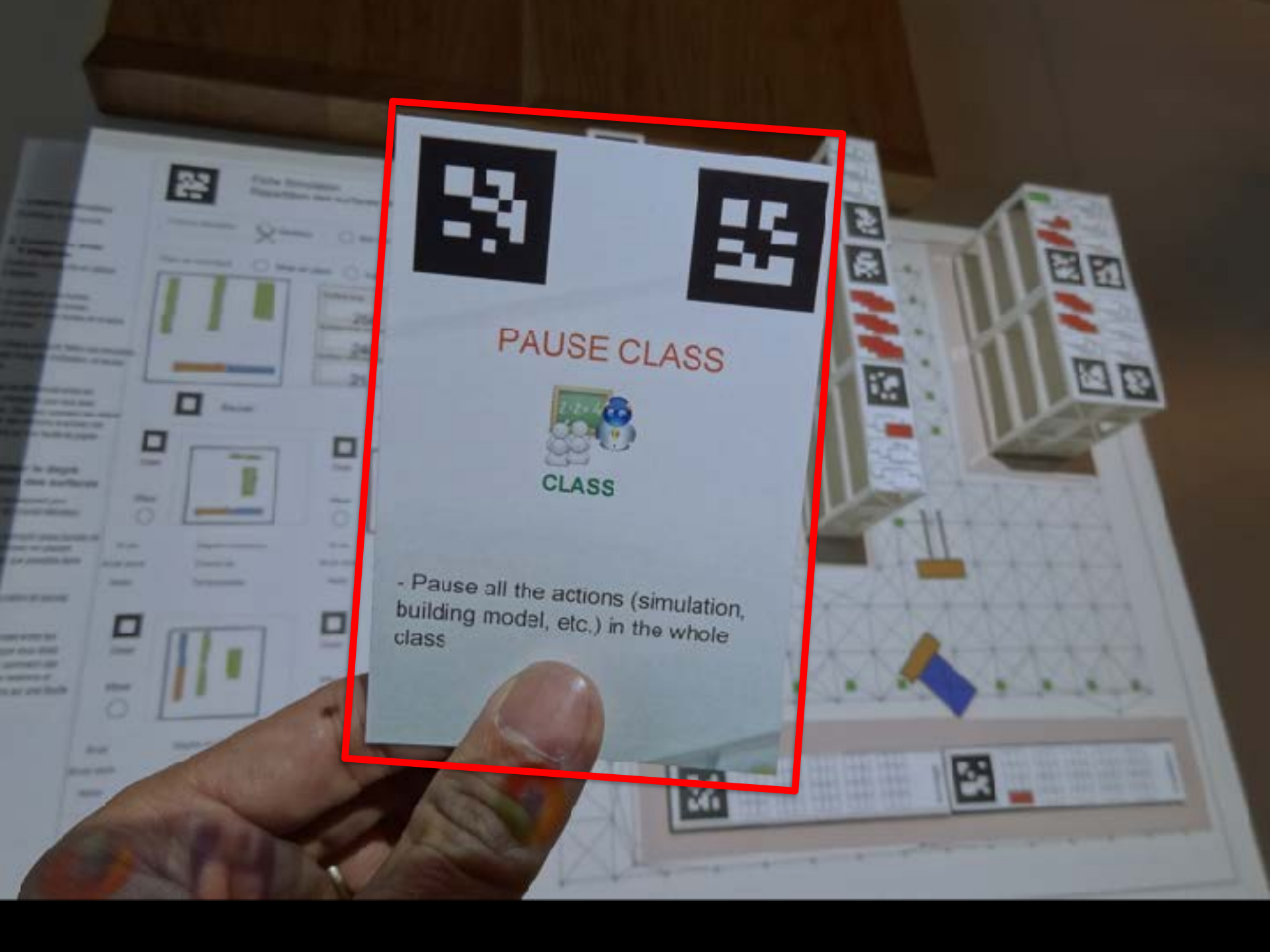


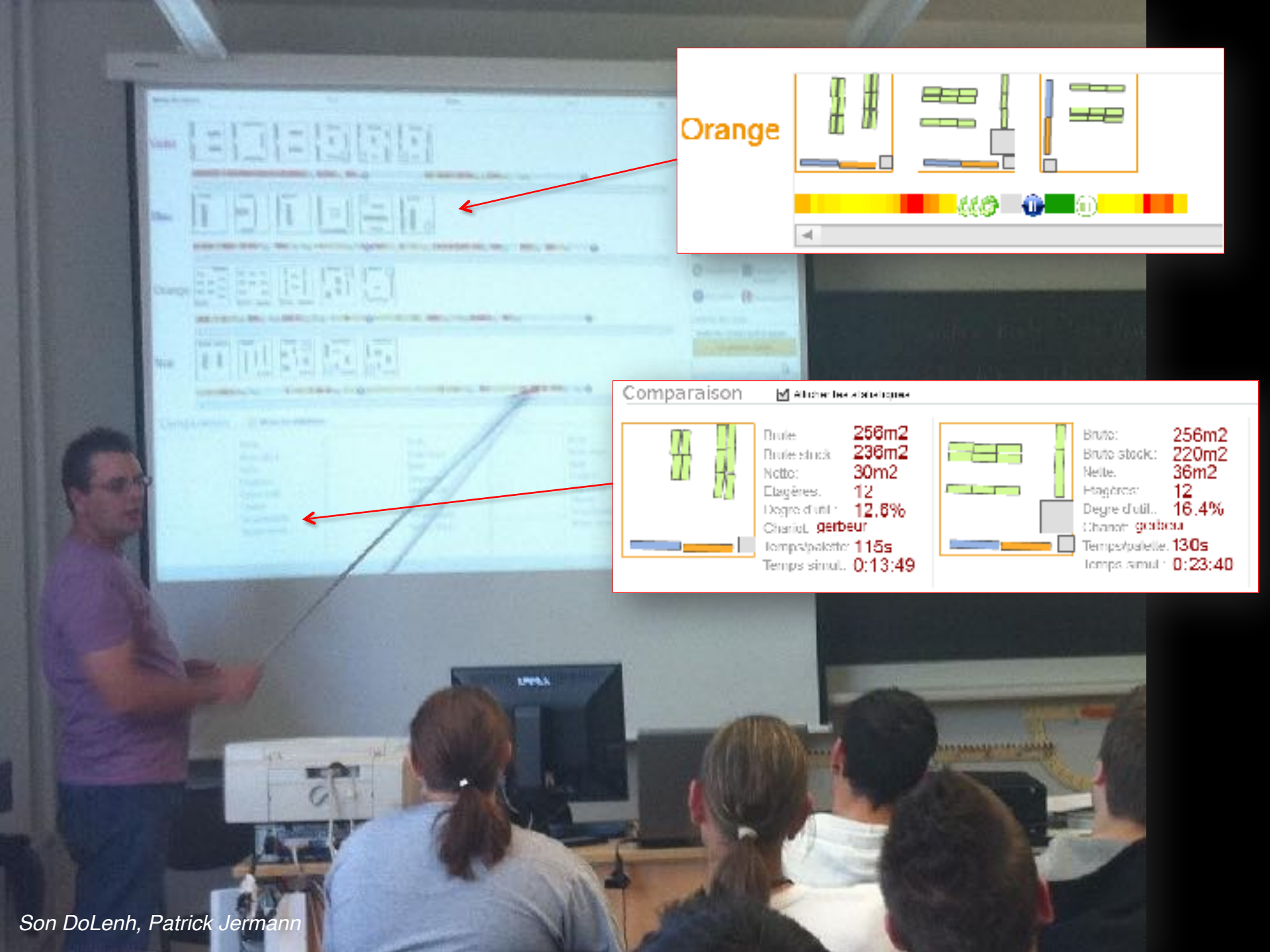

mean = 5.16 vs. mean = 5.15
F(1,14)=.06, p>.05

# “Tentation de manipulation”




Fiche Simulation
SIMULATE
GROUP
- Run a simulation of the current layout.
- Ask the students to predict before


PAUSE CLASS
CLASS
- Pause all the actions (simulation, building model, etc.) in the whole class

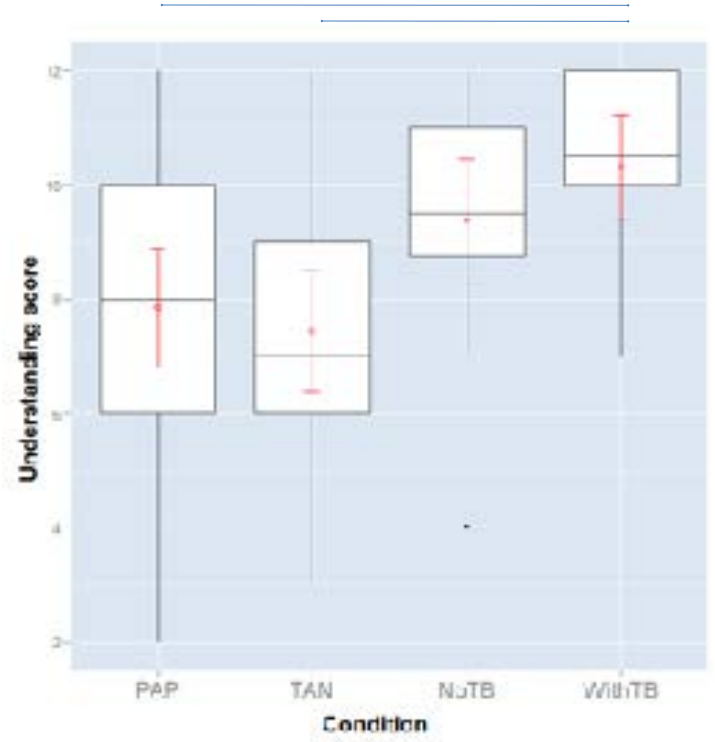


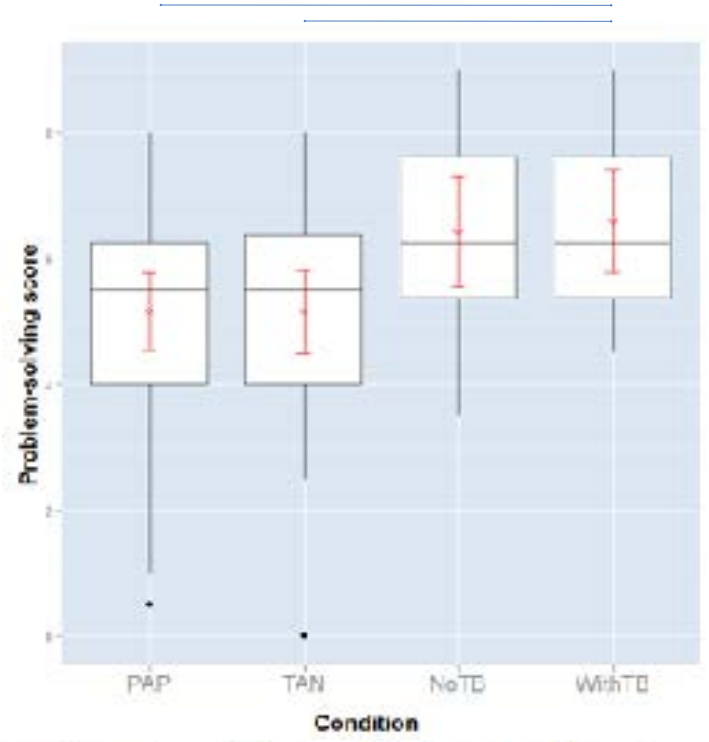

*Son DoLenh, Patrick Jermann*

# Post-test

Sign. effect in understanding

Sign. effect in problem-solving



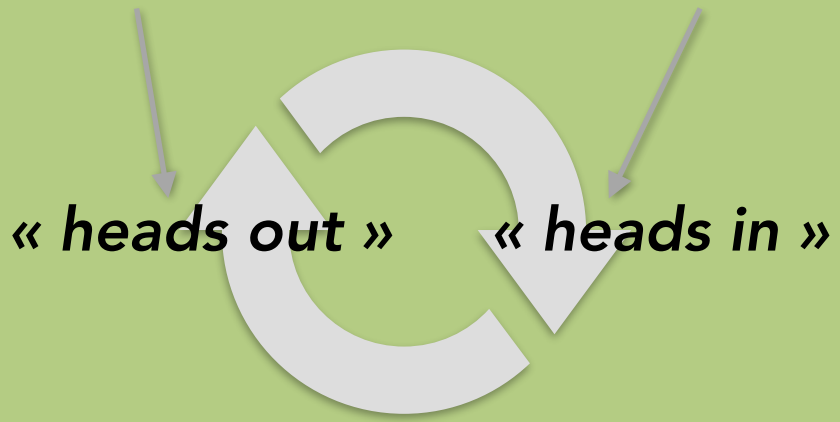

| Measures | Warehouse study's conditions | | Evaluation of TinkerLamp 2.0 conditions | |
|---|---|---|---|---|
| | Paper/pen | TinkerLamp 1.0 | TinkerLamp 2.0 WithTinkerBoard | TinkerLamp 2.0 NoTinkerBoard |
| *Understanding score* | 7.84(2.05) | 7.45(2.02) | 9.39(2.63) | 10.31(1.70) |
| *Problem-solving score* | 5.16(1.70) | 5.15(1.78) | 6.44(1.65) | 6.59(1.53) |

Exploration

Consolidation

1. Carefully design the data set
2. Comparisons, playing with differences
3. Conflict: trapping predictions
4. Advance organizers (metaphors,…)
5. **Pushing reflection**

**Reflection turns experience into knowledge**



How do people learn ? → Which technology for learning ?

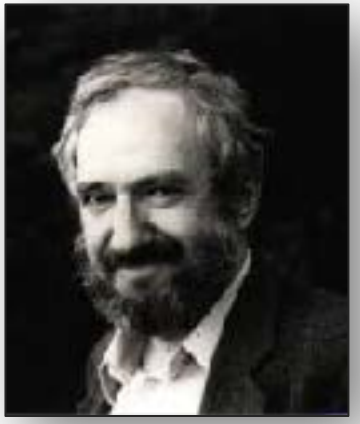
*Jean Piaget*

Scheme

If I cannot reach object A, I can take object B that connects my hand to A

Object to think with

To implement a complex program, I can decompose it into sub-problems



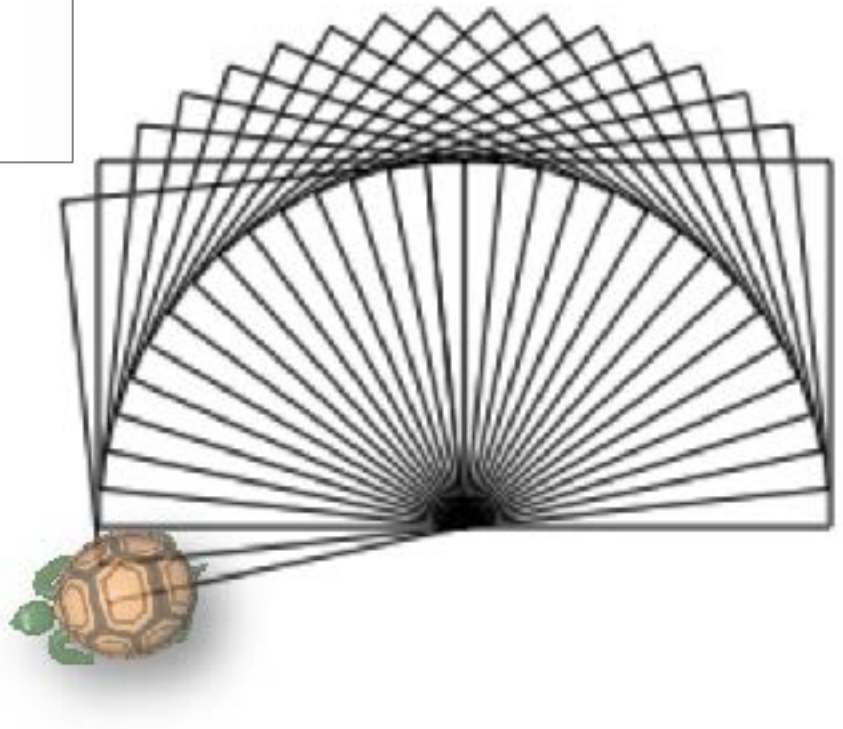
*Seymour Papert*

Function/method in programming language

# « MICROWORLD »

ExoLogO

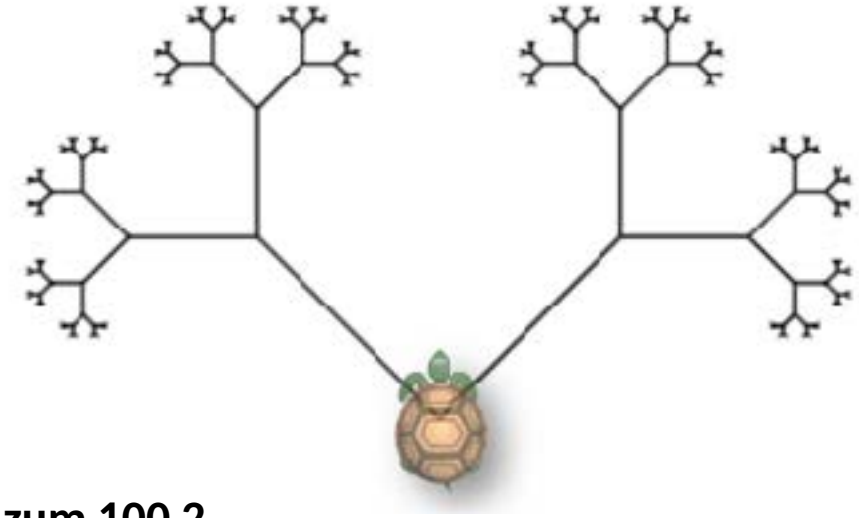
```
define "carre [[size]
[repeat 4 [forward :size wait 0.1  right 90]]]

define "fleur [[size]
[clean repeat 60 [carre :size left 6]]]


fleur 100
```



http://www.alancsmith.co.uk/logo/

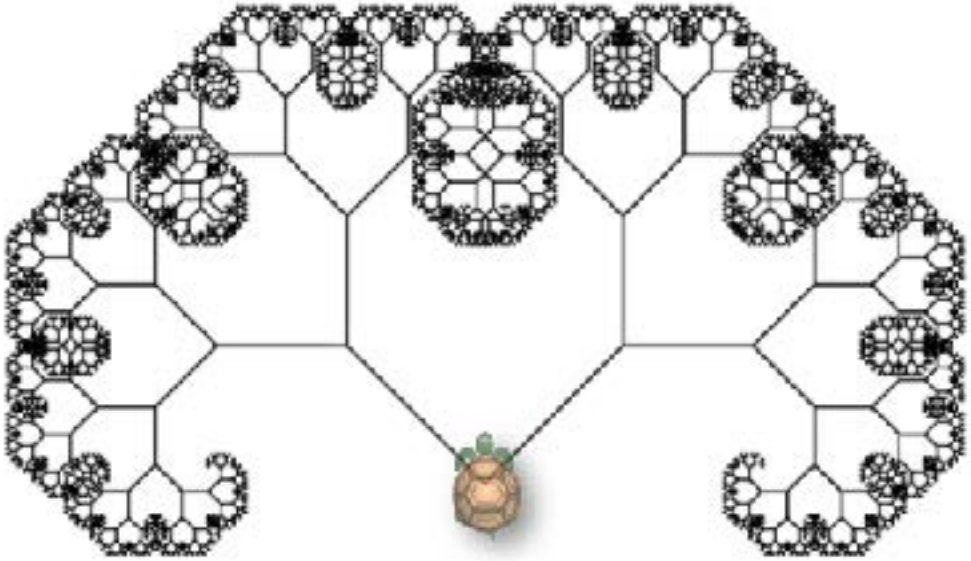
Papert, S. & Solomon, C. (1971, Twenty things to do with  a computer, AI Memo 248, MIT

```
define "Zum [[length divider]
        [if :length < 1
          [stop]
         [      left 45
                forward :length
                zum :length/:divider :divider
                back :length
                right 90
                forward :length
                zum :length/:divider :divider
                back :length
                left 45
                ]
        ]
]]
```



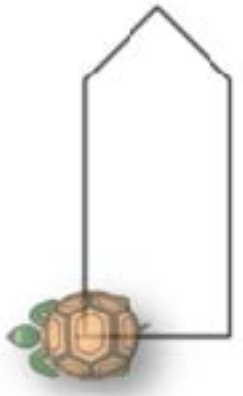
**zum 100 2**

**zum 100 1.5**

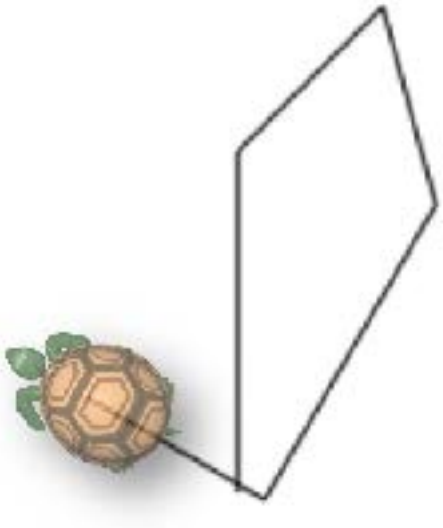


# Cognitive Conflict
# as key learning mechanism

(1) I want to get this



(2) I got that



```
define "house1 [[ ]
        [forward 100
         right 45
        forward 60
        right 120
        forward 60
        right 45
        forward 100
        right 90
        forward 60
        ]]
```

(3) The problem is here

METACOGNITION

# Cognitive Conflict
# as key learning mechanism

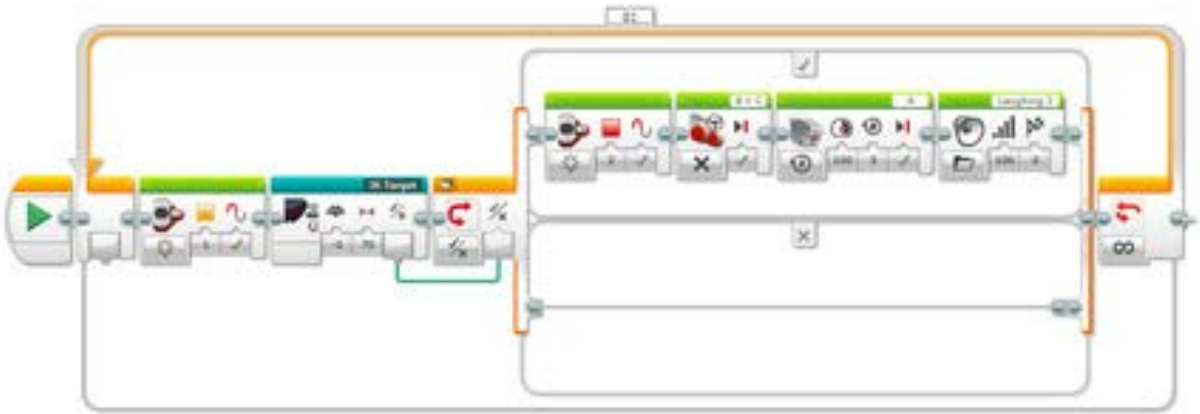
- Learning from experience
- Learning by doing
- Learning from failure
- Discovery learning

Conditions:

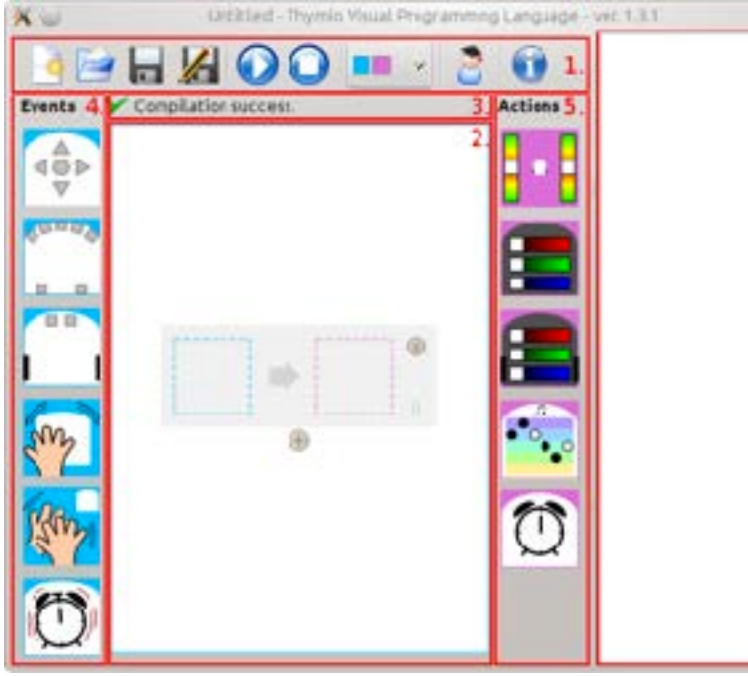
1. The conflict is detected
2. The learner finds how to solve it

*Role of the environment (sequence of projets / teacher / peer)*

# constructivism → constructionnism

http://www.srf.ch/wissen/digital/lego-mindstorms-ev3-ein-neues-hirn-fuer-komplexere-roboter




https://aseba.wikidot.com/fr:thymiovpl

https://www.youtube.com/watch?v=8RiEDT8bsOs

constructivism →
constructionnism

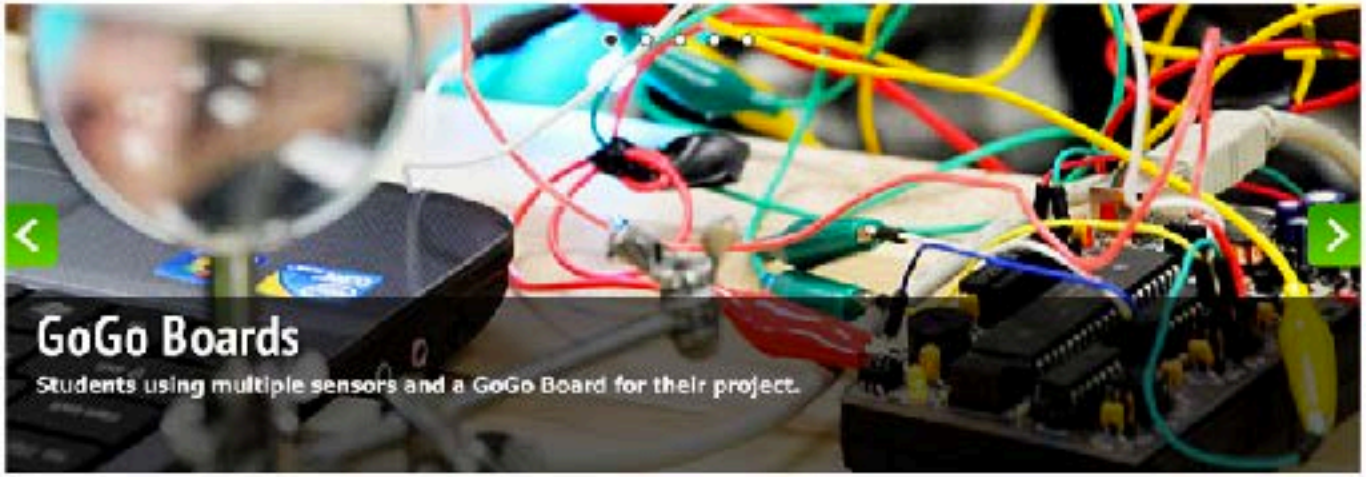
http://guerrillamakerspace.squarespace.com/space-4/

http://fablabatschool.org/

FabLab@School

Digital Fabrication
and Hands-on Learning in Education

About Blogs Photos Projects Resources




## FabLab@School

A growing network of educational digital fabrication labs that put cutting-edge technology for design and construction - such as 3D printers and laser cutters - into the hands of middle and high school students.

### WORKSHOP @ IDC 2013

A half-day workshop on Digital Fabrication and Making in Education will take place on Monday afternoon, June 24th, 2013.

This is a satellite event of the 12th International Conference on Interaction Design and Children - IDC 2013.

## Projects

Check out past student projects!

## Resources

Find useful link, activities, and tutorials here!

## FabLabs@School Around the World

CASTILLEJA SCHOOL | RUSSIA | STANFORD | THAILAND | How to Get a FabLab@School

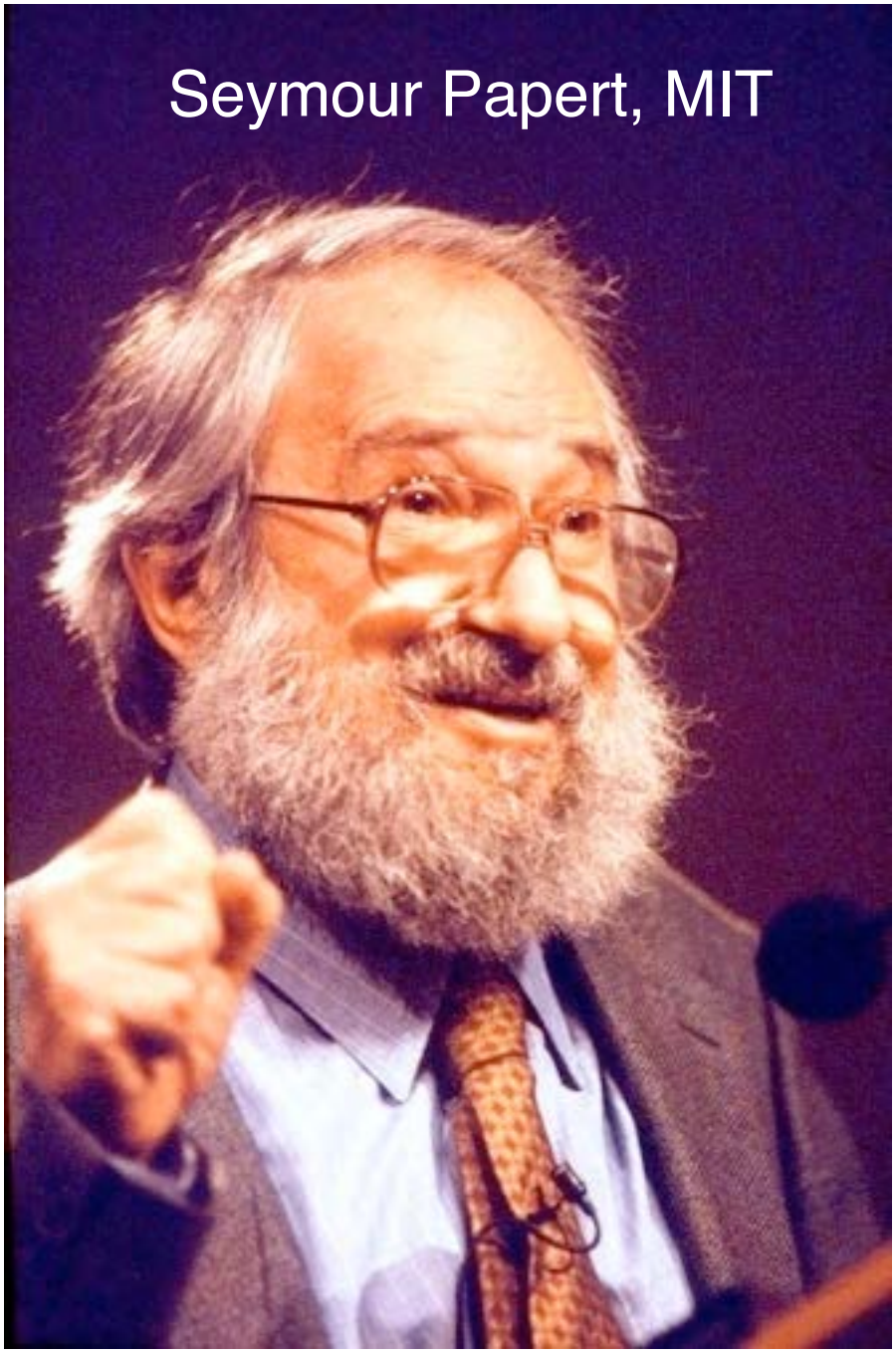
http://www.3ders.org/articles/20120701-fayetteville-free-library-launched-3d-printing-fab-lab.html

# From constructivism to constructionnism


FabLab+
Components
Toolkit

Modular
ToolKit

Tool
(Thymio, EPFL)

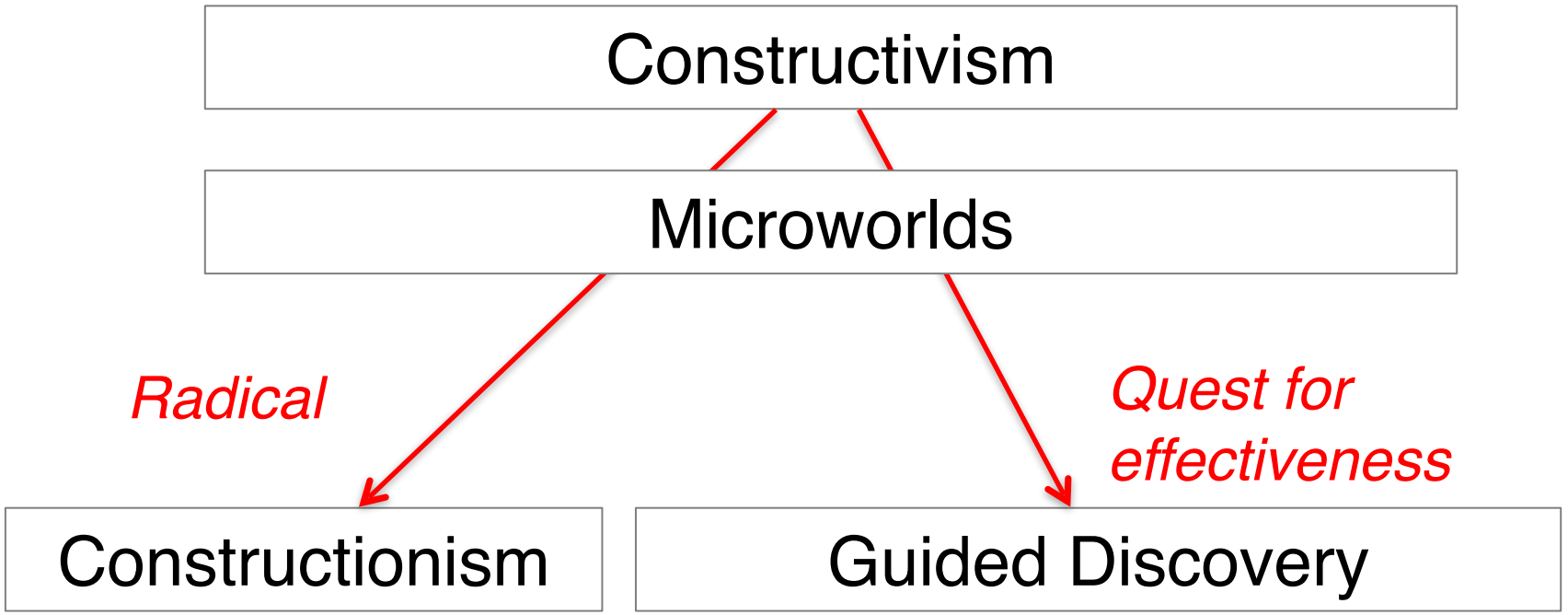



## *« Radical » branch*

The scandal of education is that every time you teach something, you deprive a [student] of the pleasure and benefit of discovery.

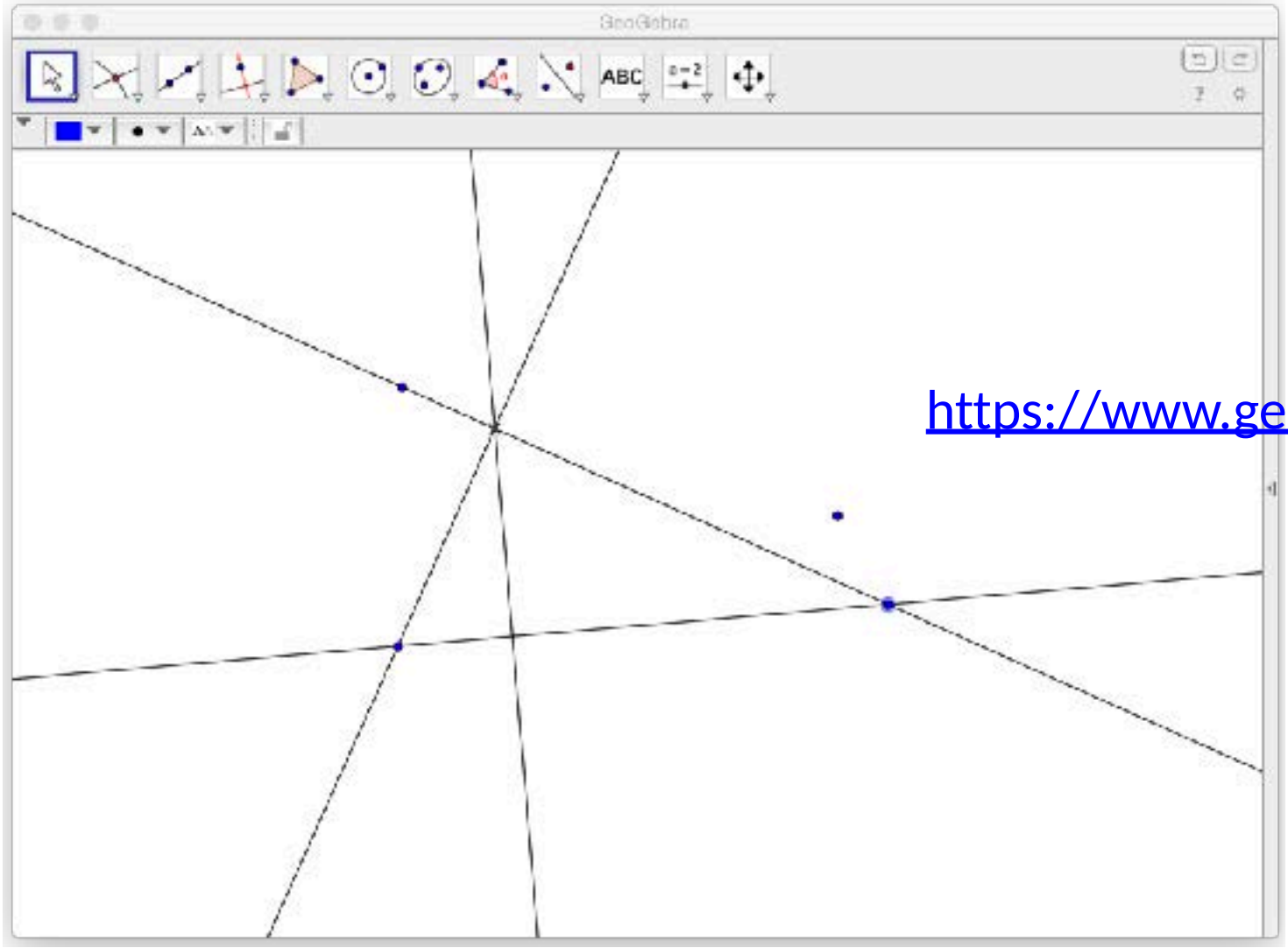
I think schools generally do an effective and terribly damaging job of teaching children to be infantile, dependent, intellectually dishonest, passive and disrespectful to their own developmental capacities.

Every maker of video games knows something that the makers of curriculum don't seem to understand. You'll never see a video game being advertised as being easy. Kids who do not like school will tell you it's not because it's too hard.




- *Content-rich microworlds*
- *Simulations*
- *Modelling*

# Quest for effectiveness: Adding Contents

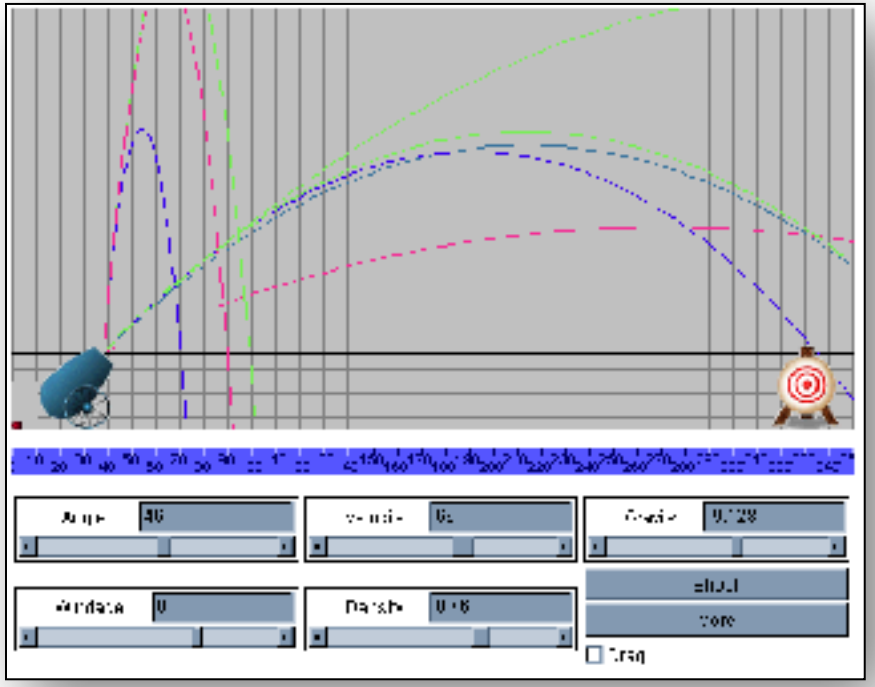



https://www.geogebra.org/

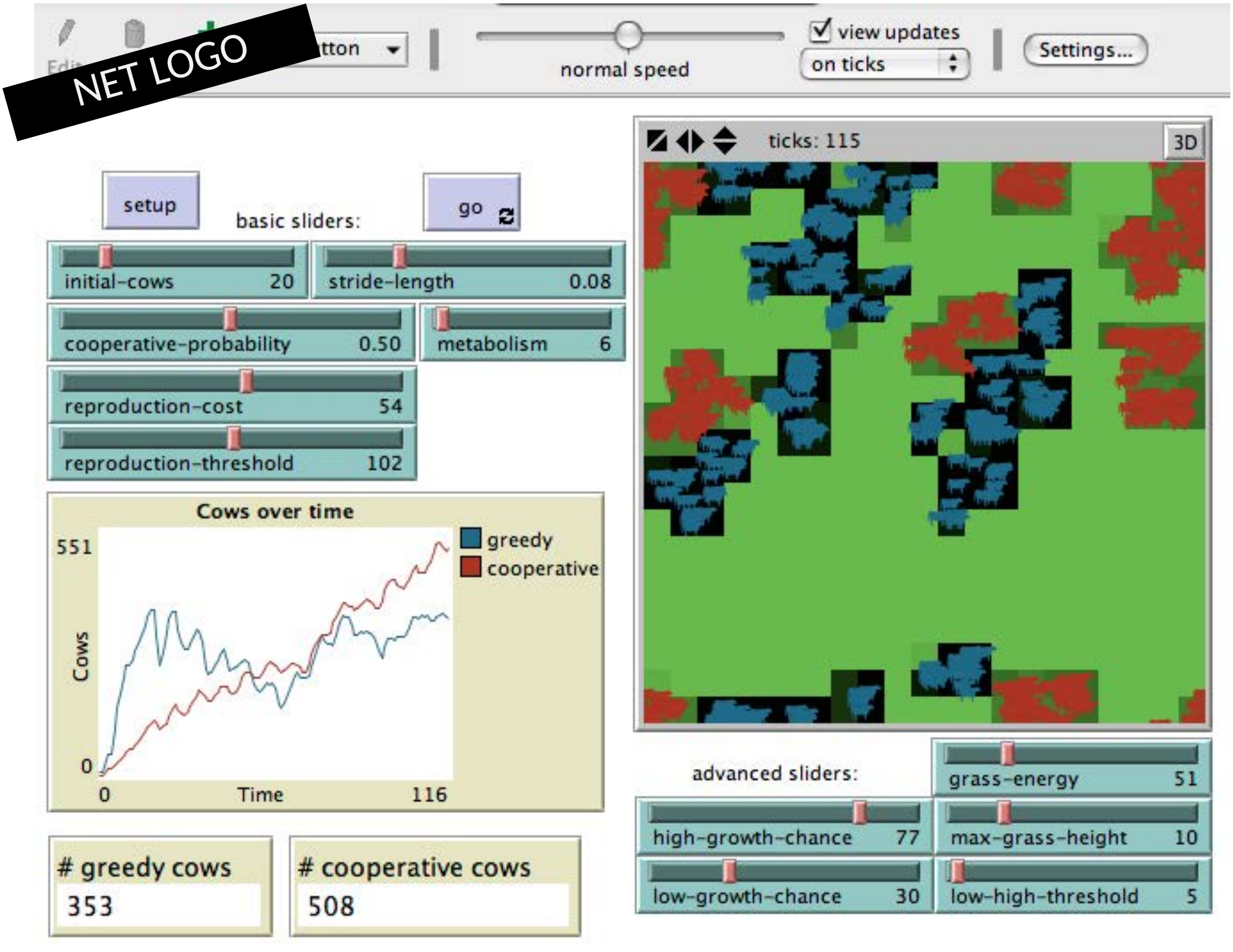
Cabri Géomètre

# Learning from Simulations

Acquire Skills



Discover underlying model


NET LOGO
normal speed
view updates
on ticks
Settings...
ticks: 115
3D
setup
basic sliders:
go
initial-cows 20
stride-length 0.08
cooperative-probability 0.50
metabolism 6
reproduction-cost 54
reproduction-threshold 102
Cows over time
551
0
Cows
0
Time
116
greedy
cooperative
advanced sliders:
grass-energy 51
high-growth-chance 77
max-grass-height 10
low-growth-chance 30
low-high-threshold 5
# greedy cows
353
# cooperative cows
508

# Learning from Simulations

More examples

An Overview paper

# Inquiry learning

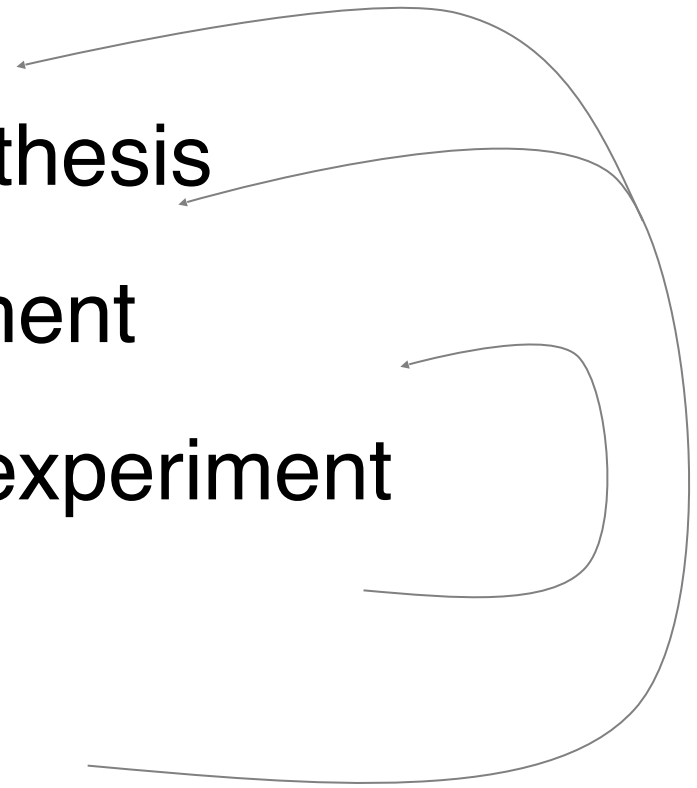
"Inquiry-based learning involves learners

- asking questions about the natural or material world,
- collecting data to answer those questions,
- making discoveries and
- testing those discoveries rigorously"

*de Jong, 2006*

# Hypothetico-deductive reasoning

1. (Raise a question)
2. Generate an hypothesis
3. Design an experiment
4. Run/simulate the experiment
5. Interpret results



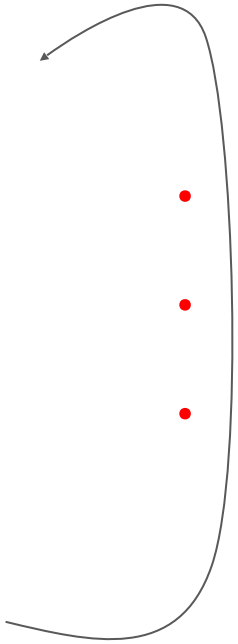
# But…

1. Question
2. Hypothesis
3. Design
4. Run
5. Interpret

- No clear hypothesis is formulated or badly formulated (42% ), i.e. no reationship between variables
- Design unconclusive experiments, students vary several parameters at at time
- Confirmation bias: to design experience that confirm the hypothesis
- 35% to 63% errors in data interpretration and graphics readings

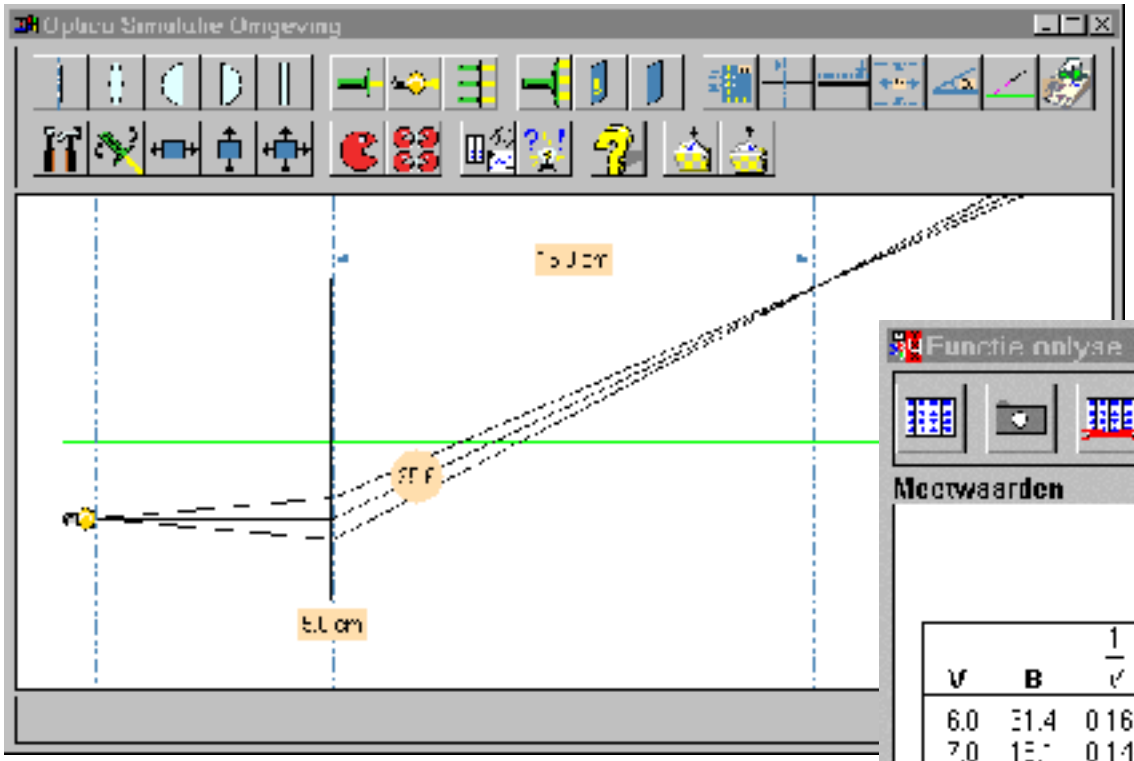
# And…

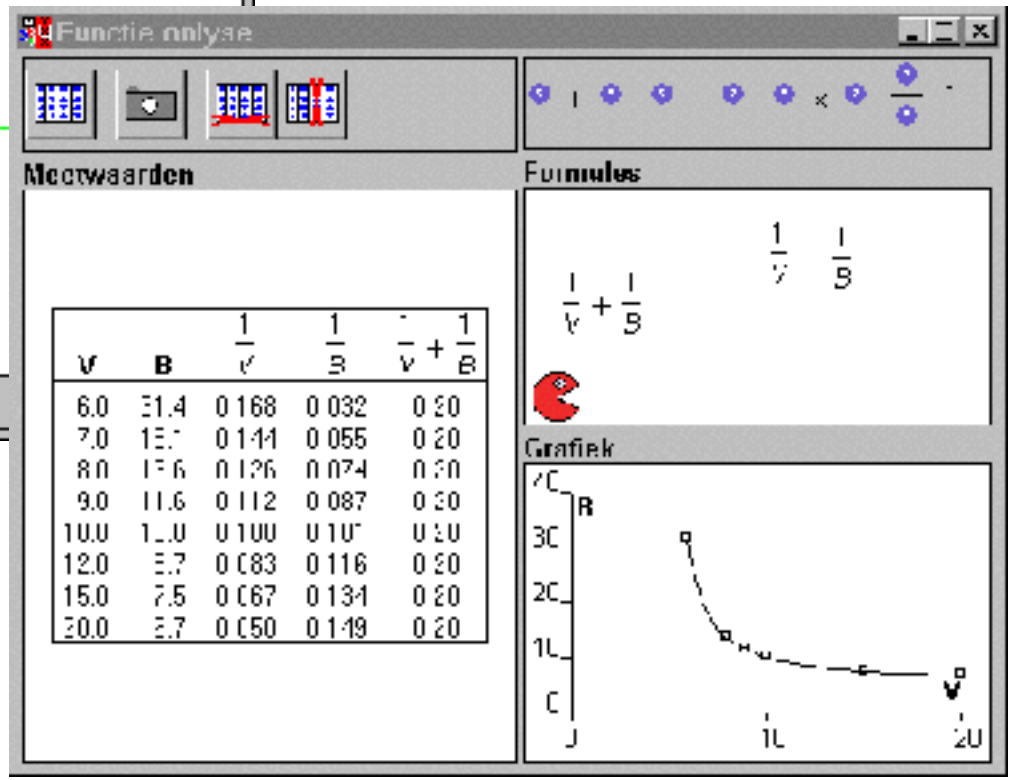
1. Question
2. Hypothesis
3. Design
4. Run
5. Interpret



- Change several parameters
- Keep hypothesis despite negative evidence
- Reject hypothesis despite positive evidence

# Example of tools to overcome these pitfalls






| V | B | 1/V | 1/B | 1/V + 1/B |
|---|---|---|---|---|
| 6.0 | 31.4 | 0.168 | 0.032 | 0.20 |
| 7.0 | 13.7 | 0.141 | 0.055 | 0.20 |
| 8.0 | 17.6 | 0.126 | 0.074 | 0.20 |
| 9.0 | 11.6 | 0.112 | 0.087 | 0.20 |
| 10.0 | 10.0 | 0.100 | 0.107 | 0.20 |
| 12.0 | 8.7 | 0.083 | 0.116 | 0.20 |
| 15.0 | 7.5 | 0.067 | 0.134 | 0.20 |
| 20.0 | 8.7 | 0.050 | 0.149 | 0.20 |

Tool to express hypotheses

# Example of scenario to overcome these pitfalls

① Ask students to write their hypothesis

② Find student with conflicting hypothesis

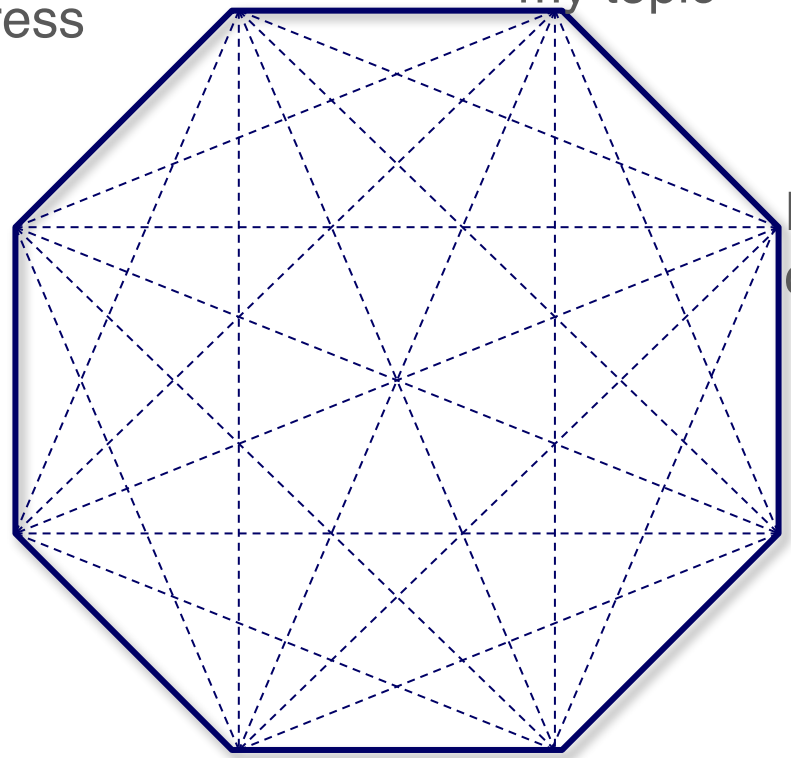
③ Ask them to find out with the simulation which hypothesis is right

Gijlers, H., & De Jong, T. (2005). The relation between prior knowledge and students' collaborative discovery learning processes. Journal of research in science teaching, 42(3), 264-282.

The effects of any learning technology depends upon the quality of classroom orchestration

# Cycle of engagement and reflection

**by Mike Sharples, Open Universty**



Find my topic

Decide my inquiry question or hypothesis

Plan my methods, equipment, actions

Collect my evidence

Analyse and represent my evidence

Respond to my question or hypothesis

Share and discuss my inquiry

Reflect on my progress

# Inquiry is a more open process than simulations

A lesson is not inquiry based if:

- Students know what results they are supposed to get
- The questions and steps are pre-determined for them
- The teacher is working harder than the students

http://www.stemmom.org/2012/03/what-inquiry-is-not.html


Sharples, M., Collins, T., Fei\sstM., Gaved, M., Mulholland, P., Paxton, M., & Wright, M. (2011) A Laboratory of Knowledge-Making for Personal Inquiry Learning. Artificial Intelligence in Education.

ScienceScope

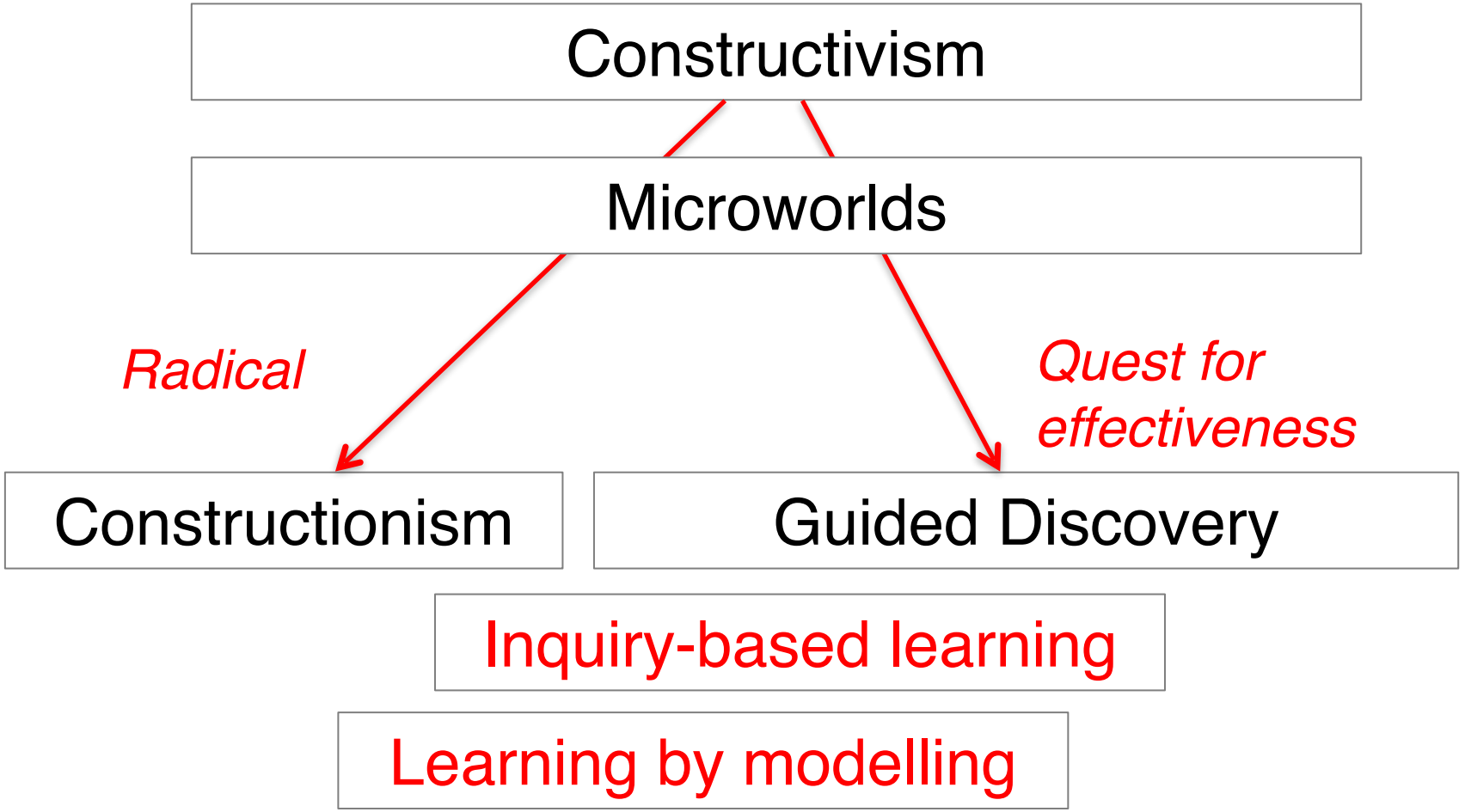
Linking ICT With Science Education

http://www.sciencescope.co.uk/Pages/SensorCategories.aspx

## Sensors

- 3 cm Wave Signal Strength
- AC MilliVolt
- Accelerometer 2 axis
- Accelerometer 3 axis
- Altimeter
- Anemometer
- Carbon Dioxide
- Carbon Dioxide Replacement Cell
- Carbon Monoxide
- Carbon Monoxide Replacement Cell
- Charge Sensor
- Conductivity
- Current ±1 A
- Current ±1 mA
- Current ±10 A
- Current ±100 mA
- Distance IR
- Distance Ultrasonic Basic
- Electrosmog advanced
- Electrosmog Basic
- Flow Advanced
- Flow Meter
- Force Dual Range
- Frequency
- Humidity
- IR Irradiance
- Joulemeter
- Light (Advanced)
- Light (General Purpose)
- Magnetic Field with 100mT Probe
- Magnetic Probe 30 mT
- Nitrogen Dioxide
- Oxygen Atmospheric
- Oxygen Atmospheric Cell
- Oxygen Probe - Dissolved
- pH Interface
- pH Probe Sensor - advanced
- pH Probe Sensor - basic
- Pressure (Absolute 0 - 700 Kpa)
- Pressure (Absolute 0 - 200 KPa)

1 2

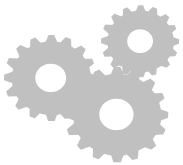

Constructivism
Microworlds
Radical
Quest for effectiveness
Constructionism
Guided Discovery
Inquiry-based learning
Learning by modelling

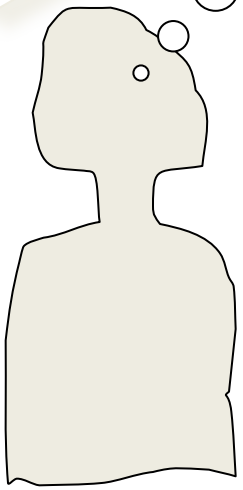
# Learning from simulations

Mental Model

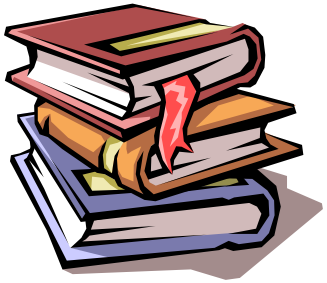
*Hypothetic-deductive reasoning*

Computationa Model





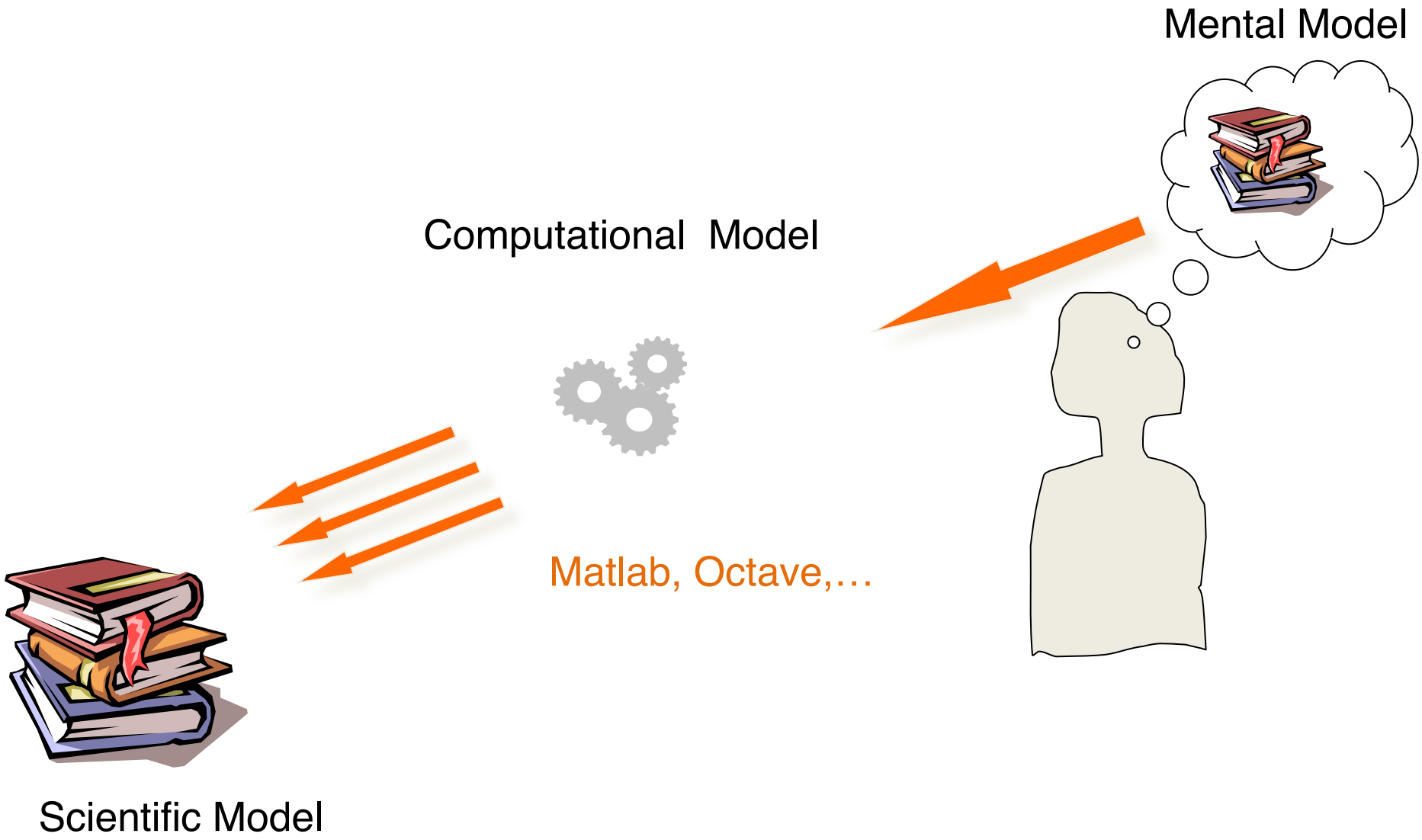
Scientific Model



Didatic Transformation: simplify it for didactic reasons

Computation transformation: approximate it for computational reasons

# Learning from modelling



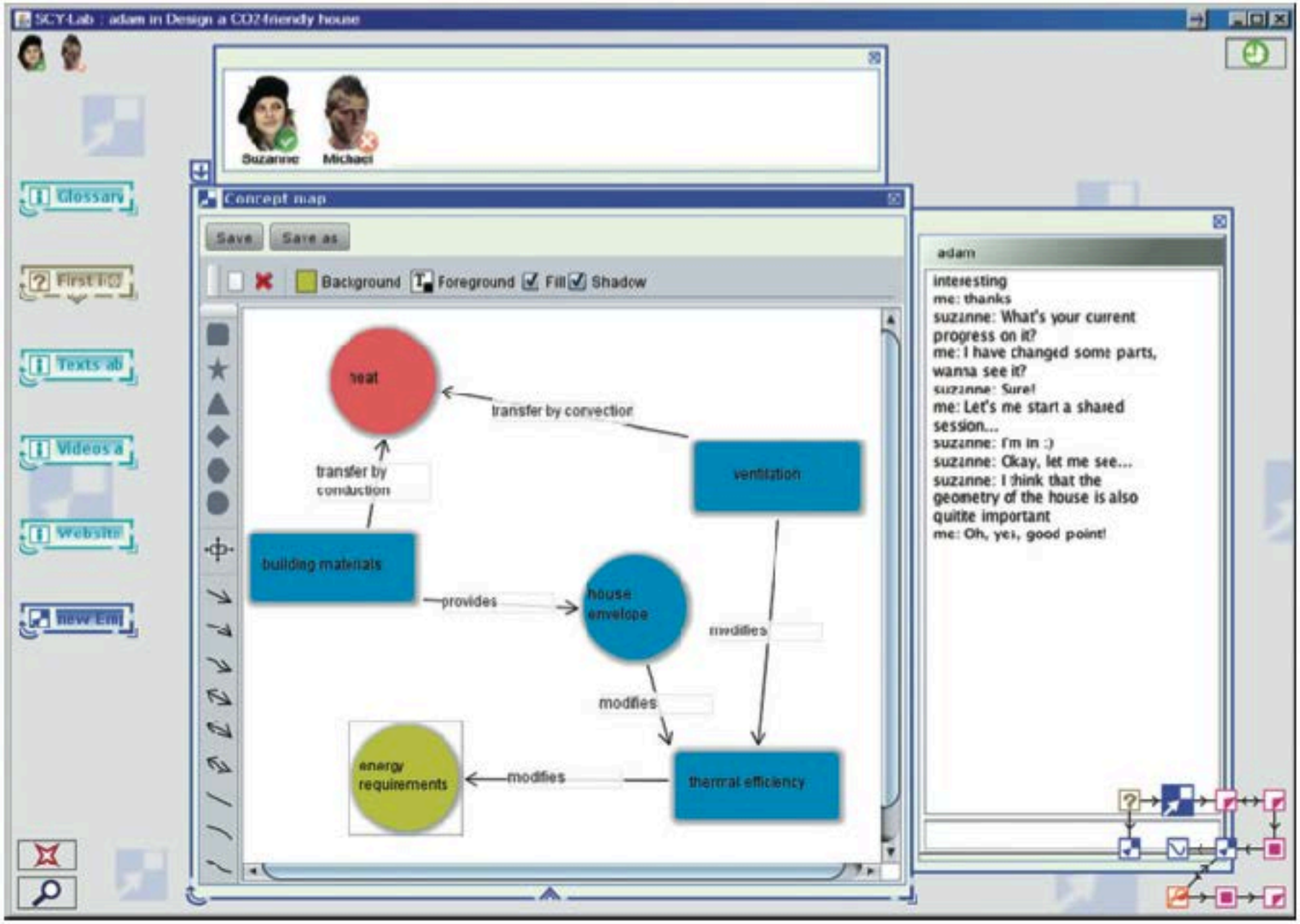
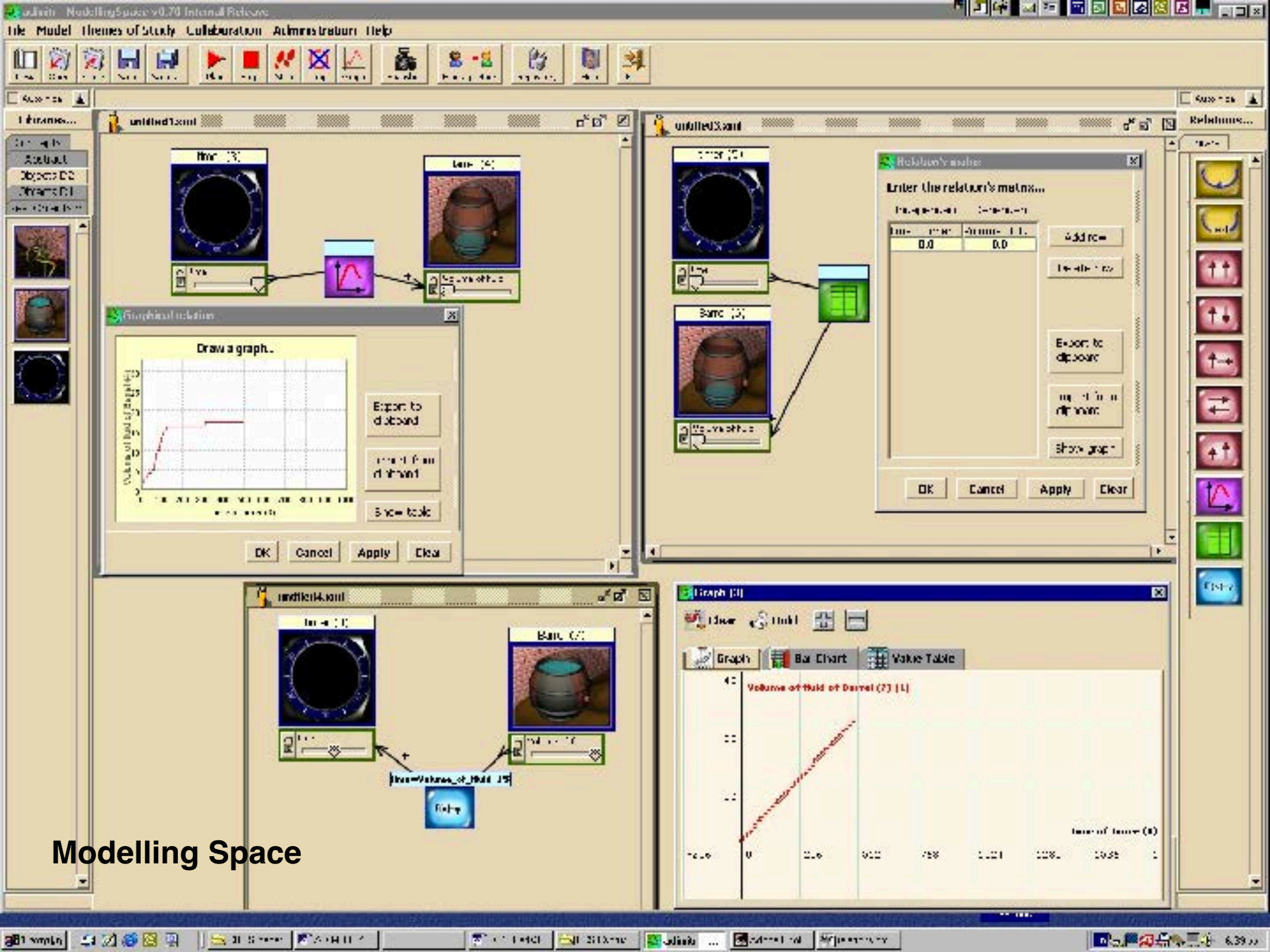
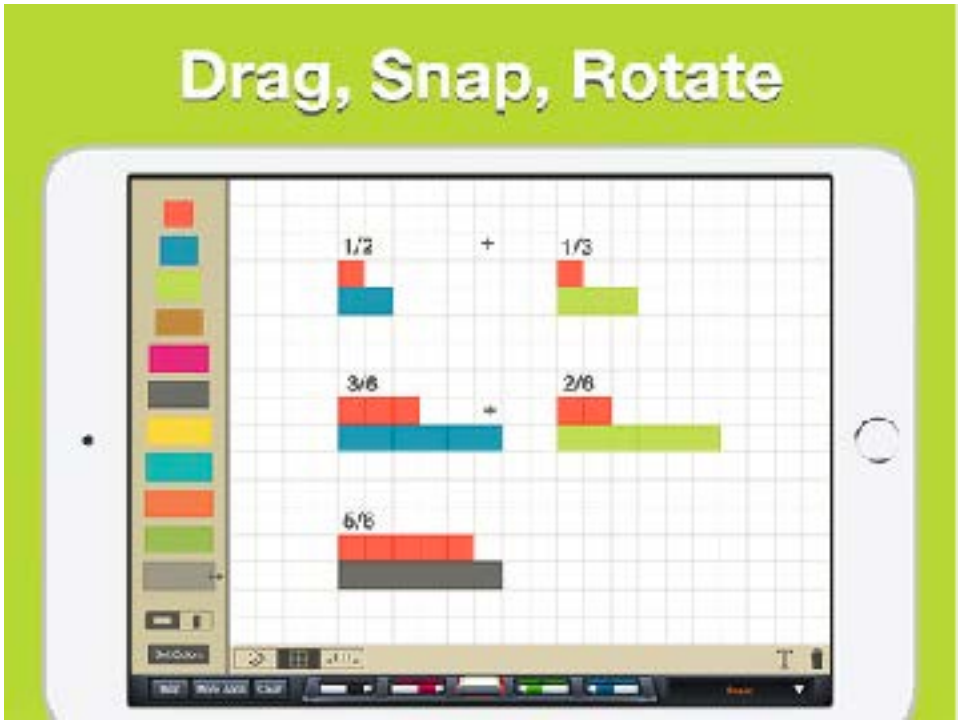



*Figure 2: A SCY concept map with drawers attached. Available peers are above and a SCY chat is active to the right*


File Model Themes of Study Collaboration Administration Help
Draw a graph...
Export to clipboard
Show table
OK
Cancel
Apply
Clear
Enter the relation's matrix...
Add row
Export to clipboard
Show graph
OK
Cancel
Apply
Clear
Graph
Bar Chart
Value Table
Modelling Space

# Manipulating real or virtual objects ?

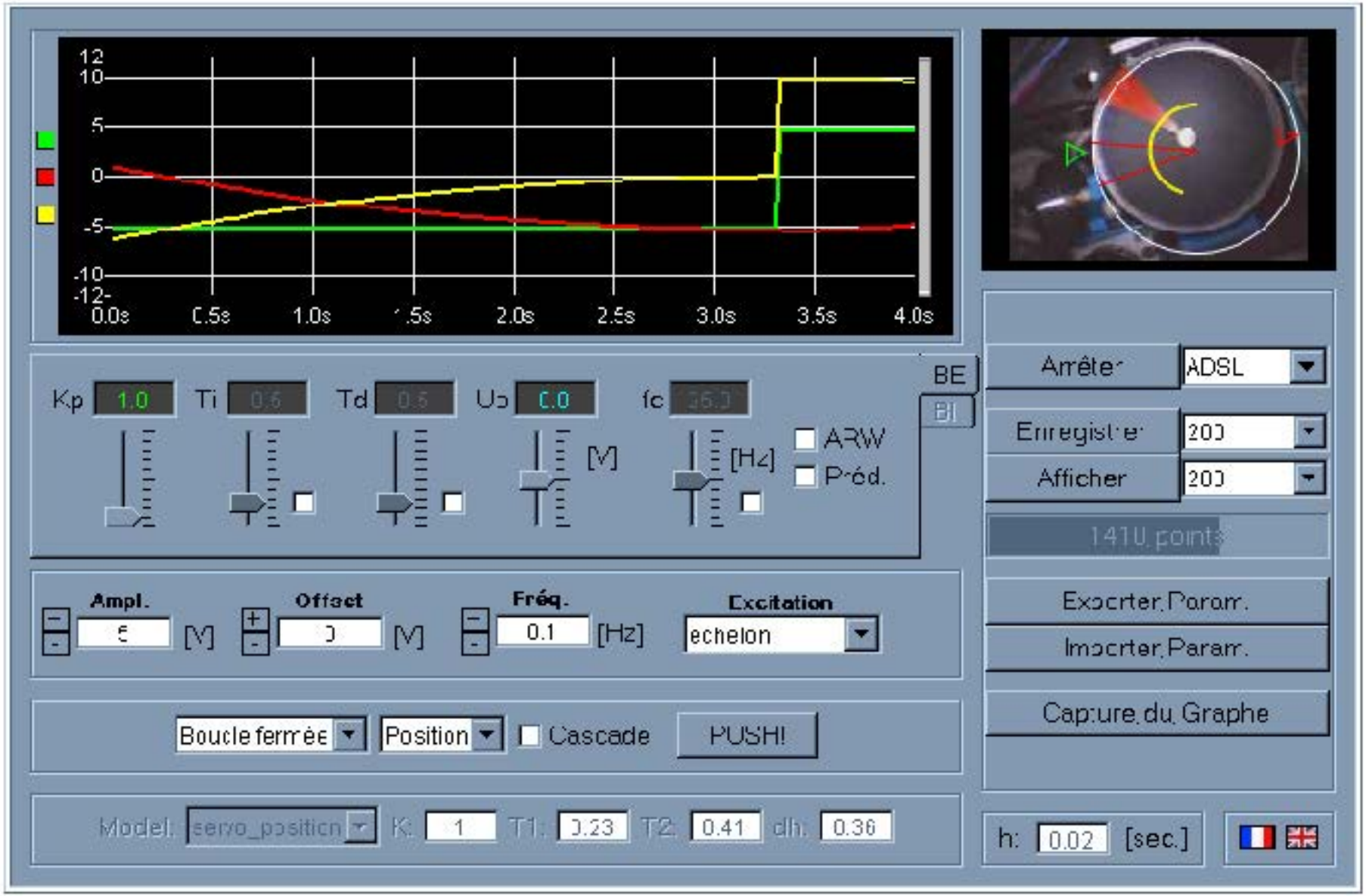
Cuisenaire Rods




iPad Version

https://itunes.apple.com/gb/app/number-rods/id536204074?mt=8

# The real-virtual debate: offer both!




http://emersion.epfl.ch/mechatronics/index.html

For you project, look for reusable exploration/simulation/problem solving activities

# Summary:

1. People don't learn by being taught but by adapting their knowledge structures through interaction with artefacts. Educational philosophy: from telling students what to do to letting them invent things
2. In practice, this approach does not work very well without external support and requires talented teachers. Learning from simulation requires inquiry skills. Training these transversal skills are key goals of any education
3. Evolution of pedagogical methods from building mental schemes to building concrete objects. Digital artefacts offer rich interactions but digital education is not limited to virtual object. Tangible interfaces and augmented reality open it to physical manipulation.