Building engaging and effective instruction: Does inquiry learning alone suffice to do the job?

Ton de Jong
University of Twente

INHERE conference Munich
March 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731685.

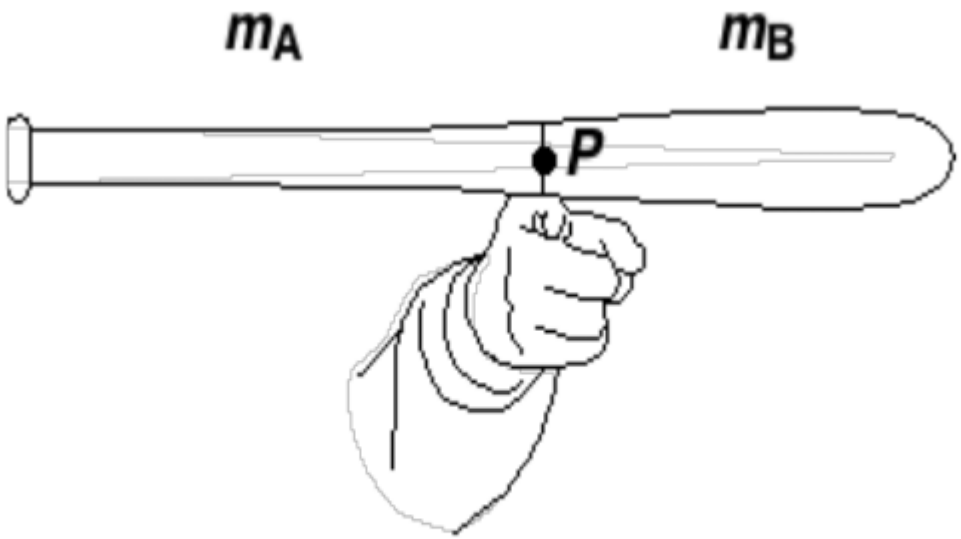
Active – Engaged learning with online labs

- Is there a reason for change in science education?
- Active and engaged learning
- Learning with online labs
- The Go-Lab ecosystem
- Some future developments
- Is learning with online labs effective?

nextlab

Is there a reason for change in science education?

Baseball bat problem



Compare the mass to the left and right of the balance point. Explain.

Ortiz, L. G., Heron, P. R. L., & Shaffer, P. S. (2005). Student understanding of static equilibrium: Predicting and accounting for balancing. *American Journal of Physics*, *73*, 545-553.

Baseball bat problem

❖ Correct response:

Mass and distance are both factors whose product must be an equal amount on both sides. Thus m_a is less.

❖ Typical incorrect response:

If the bat is to be balanced, there must be an equal amount of mass to the left and right point of P.

Correct responses

Study Ortiz: University of Washington first year engineering, physics, math and computer science with high school physics experience (N = 674)	**20%**
Primary school teachers (N = 582)	**3%**
Lower secondary physics teachers (N = 167)	**6%**
University physics students in introductory calculus-based Mechanics (N => 1000 in 4 different countries)	**14%**
University engineering students in introductory engineering statics (N > 2500 in 4 different countries)	**18%**

From Costas Constantinou. EARLI presidential address 2015. https://www.researchgate.net/publication/282440831_EARLI_2015_Presidential_Address_Presentation_on_Modeling_Based_Learning_in_Science

Many similar results ....

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1, 205-221.

Trowbridge, D. E., & McDermott, L. C. (1980). Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics*, *48*, 1020-1028.

Gunstone, R. F., & White, R. T. (1981). Understanding of gravity. *Science Education*, *65*, 291-299.

Cros, D., Chastrette, M., & Fayol, M. (1988). Conceptions of second year university students of some fundamental notions in chemistry. *International Journal of Science Education*, *10*, 331-336.

Kruger, C. J., Summers, M. K., & Palacio, D. J. (1990). An investigation of some English primary school teachers' understanding of the concepts force and gravity. *British Educational Research Journal*, *16*, 383-397.

Bodner, G. M. (1991). I have found you an argument: The conceptual knowledge of beginning chemistry graduate students. *Journal of Chemical Education*, *68*, 385.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education*, *69*, 191.

Smith, K. J., & Metz, P. A. (1996). Evaluating student understanding of solution chemistry through microscopic representations. *Journal of Chemical Education*, *73*, 233.

Lin, H., Cheng, H., & Lawrenz, F. (2000). The assessment of students and teachers' understanding of gas laws. *Journal of Chemical Education*, *77*, 235.

Burgoon, J. N., Heddle, M. L., & Duran, E. (2010). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Teacher Education*, *21*, 859-872

Trouille, L. E., Coble, K., Cochran, G. L., Bailey, J. M., Camarillo, C. T., Nickerson, M. D., & Cominsky, L. R. (2013). Investigating student ideas about cosmology III: Big bang theory, expansion, age, and history of the universe. *Astronomy Education Review*, *12*

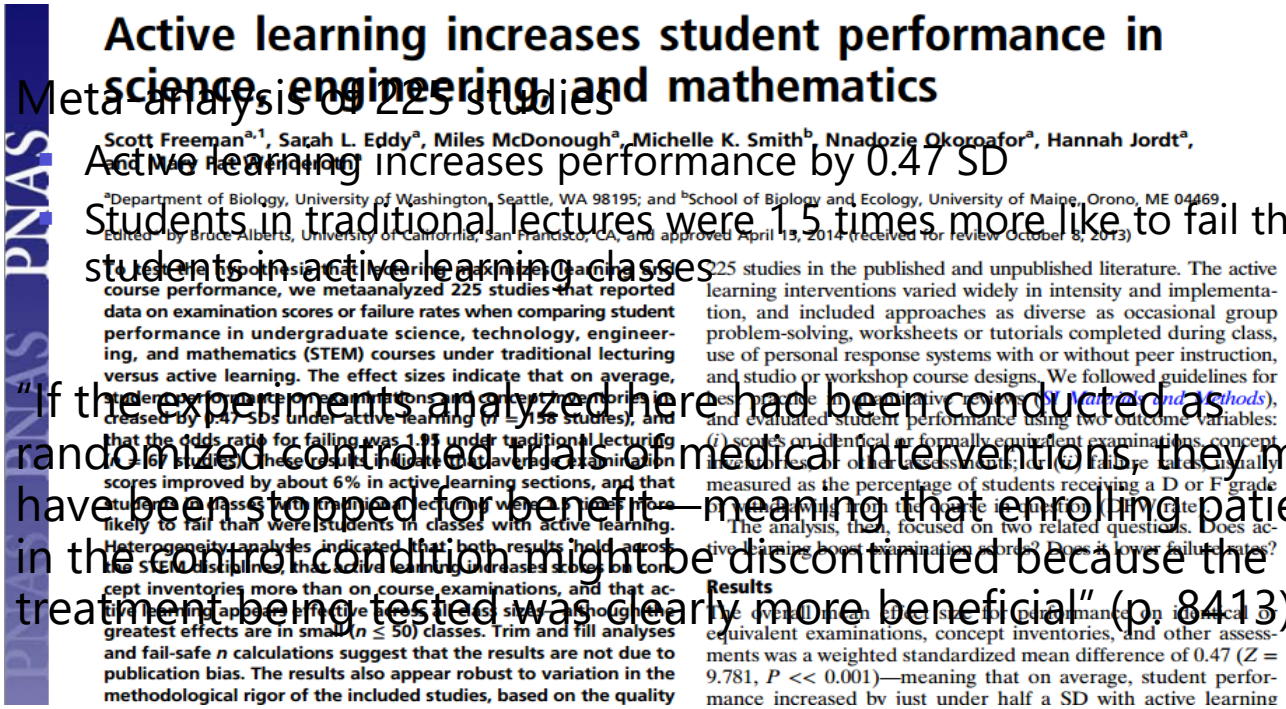
Etc.

nextlab

The proposed solution

Engaged learning – effect

- Meta-analysis of 225 studies
  - Active learning increases performance by 0.47 SD
  - Students in traditional lectures were 1.5 times more like to fail than students in active learning classes
- "If the experiments analyzed here had been conducted as randomized controlled trials of medical interventions, they may have been stopped for benefit—meaning that enrolling patients in the control condition might be discontinued because the treatment being tested was clearly more beneficial" (p. 8413)



PNAS

Active learning increases student performance in science, engineering, and mathematics

Scott Freeman[a,1], Sarah L. Eddy[a], Miles McDonough[a], Michelle K. Smith[b], Nnadozie Okoroafor[a], Hannah Jordt[a], and Mary Pat Wenderoth[a]

[a]Department of Biology, University of Washington, Seattle, WA 98195; and [b]School of Biology and Ecology, University of Maine, Orono, ME 04469.

Edited by Bruce Alberts, University of California, San Francisco, CA, and approved April 13, 2014 (received for review October 8, 2013)

To test the hypothesis that lecturing maximizes learning and course performance, we metaanalyzed 225 studies that reported data on examination scores or failure rates when comparing student performance in undergraduate science, technology, engineering, and mathematics (STEM) courses under traditional lecturing versus active learning. The effect sizes indicate that on average, student performance on examinations and concept inventories increased by 0.47 SDs under active learning ($n = 158$ studies), and that the odds ratio for failing was 1.95 under traditional lecturing ($n = 67$ studies). These results indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning. Heterogeneity analyses indicated that both results hold across the STEM disciplines, that active learning increases scores on concept inventories more than on course examinations, and that active learning appears effective across all class sizes—although the greatest effects are in small ($n \leq 50$) classes. Trim and fill analyses and fail-safe n calculations suggest that the results are not due to publication bias. The results also appear robust to variation in the methodological rigor of the included studies, based on the quality

225 studies in the published and unpublished literature. The active learning interventions varied widely in intensity and implementation, and included approaches as diverse as occasional group problem-solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs. We followed guidelines for best practice in quantitative reviews (*SI Materials and Methods*), and evaluated student performance using two outcome variables: (*i*) scores on identical or formally equivalent examinations, concept inventories, or other assessments; or (*ii*) failure rates, usually measured as the percentage of students receiving a D or F grade or withdrawing from the course in question (DFW rate).

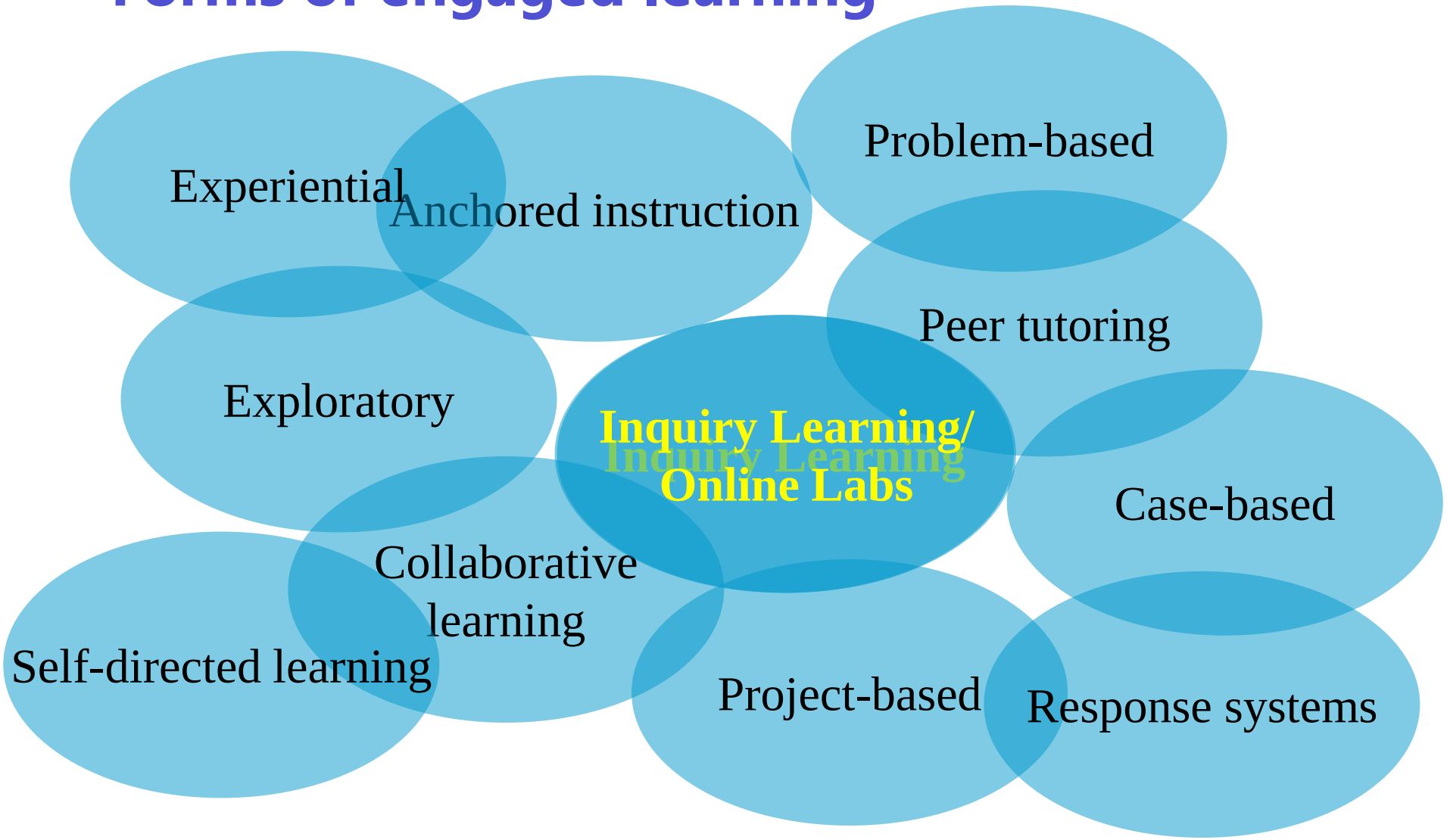
The analysis, then, focused on two related questions. Does active learning boost examination scores? Does it lower failure rates?

Results

The overall mean effect size for performance on identical or equivalent examinations, concept inventories, and other assessments was a weighted standardized mean difference of 0.47 ($Z = 9.781$, $P << 0.001$)—meaning that on average, student performance increased by just under half a SD with active learning

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*, 8410-8415.

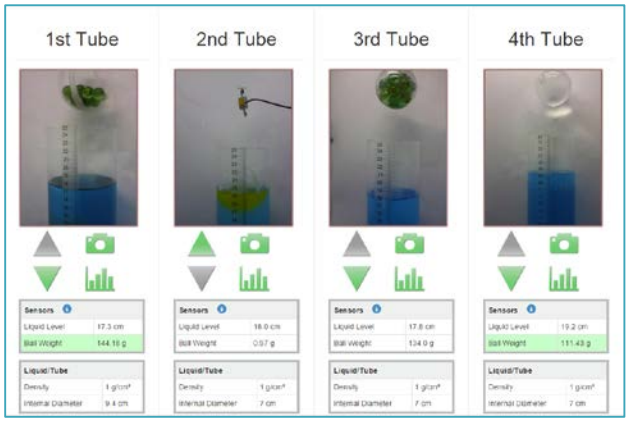
Forms of engaged learning

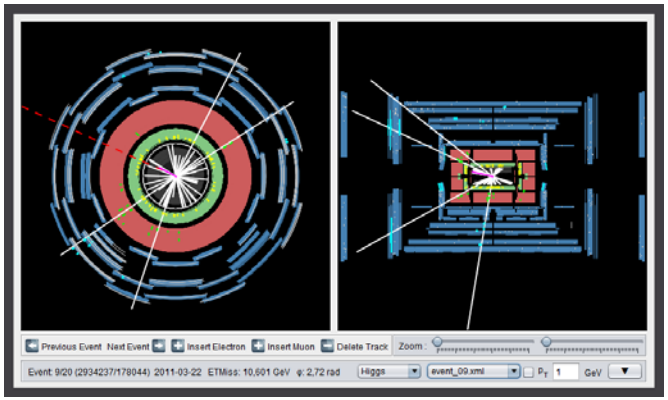


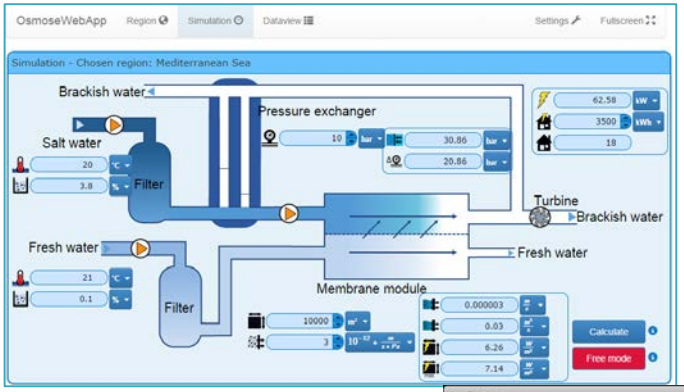
nextlab

Learning with online labs

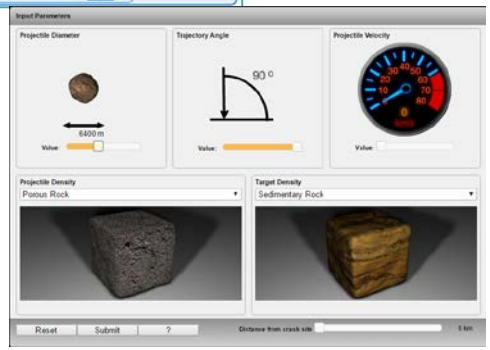
Online labs


1st Tube
2nd Tube
3rd Tube
4th Tube

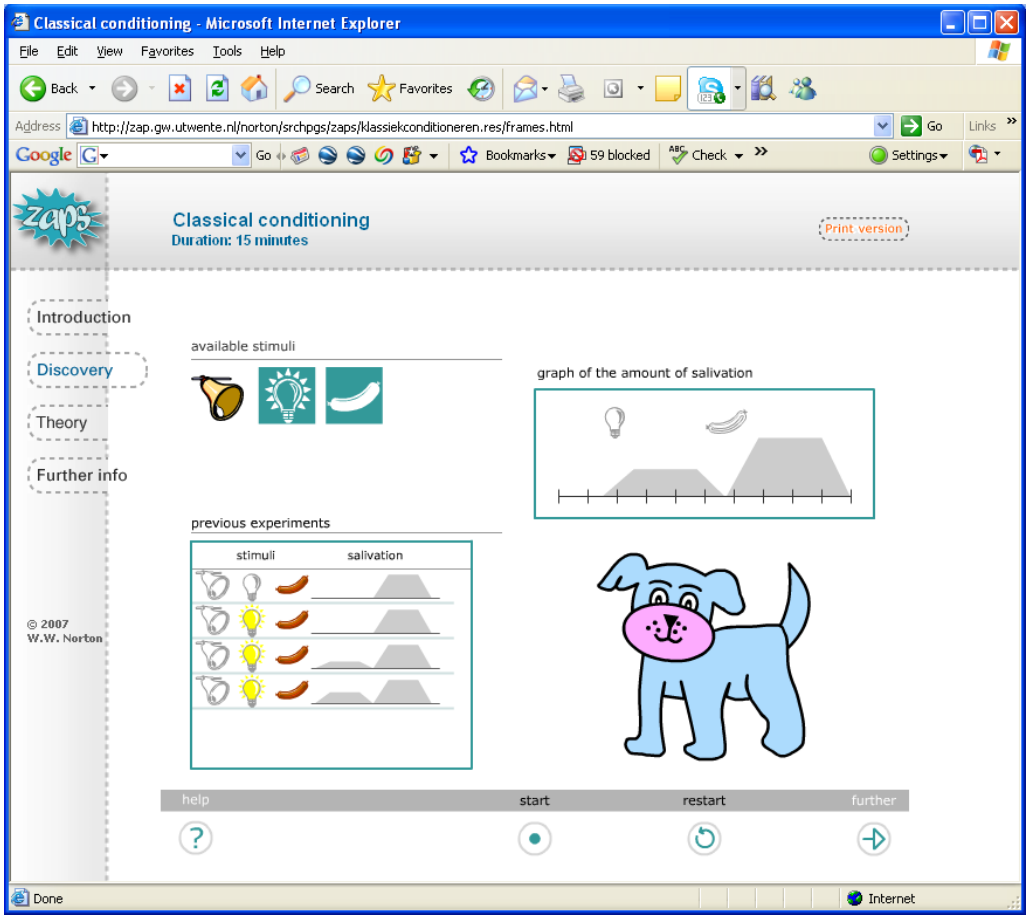

Previous Event
Next Event
Insert Electron
Insert Muon
Delete Track
Zoom


OsmoseWebApp
Simulation - Chosen region: Mediterranean Sea
Brackish water
Salt water
Filter
Pressure exchanger
Turbine
Brackish water
Fresh water
Fresh water
Filter
Membrane module
Calculate
Free mode

Density
Floating and sinking
Relative density
Archimedes
Forces
Object properties
Mass
400.00 g
Volume
300.00 cm3
Density
1.33 g/cm3 Plastic
Fluid
0.79 g/cm3 Acetone
Lab
A
B
C
D
E
Run
Refresh
Delete all
Add


Projectile Diameter
Trajectory Angle
Projectile Velocity
Projectile Density
Porous Rock
Target Density
Sedimentary Rock
Reset
Submit

An example from psychology



Inquiry as engaged learning

Expository methods (teaching)	Inquiry methods (learning)
• Teacher explains – students do exercises (ready made science)	• Students do explorations first and design concepts and laws together with their teachers (science-in-the making)
• First: presentation of scientific principles (lecture) • Then: experiment to verify (confirm) the principle (laboratory)	• Students construct (not only confirm) meaning • No clear separation between the lecture and the lab

Schuster, D., Cobern, W. W., Adams, B. A. J., Undreiu, A., & Pleasants, B. (in press). Learning of core disciplinary ideas: Efficacy comparison of two contrasting modes of science instruction. *Research in Science Education*.

Trout, L. Lee, C., Moog, R., Ricky, D. (2008). Inquiry learning: What is it? How do you do it? In: *Chemistry in the National Science Standards, 2nd Edition*, S.L. Bretz (Ed.). Washington, DC: American Chemical Society.

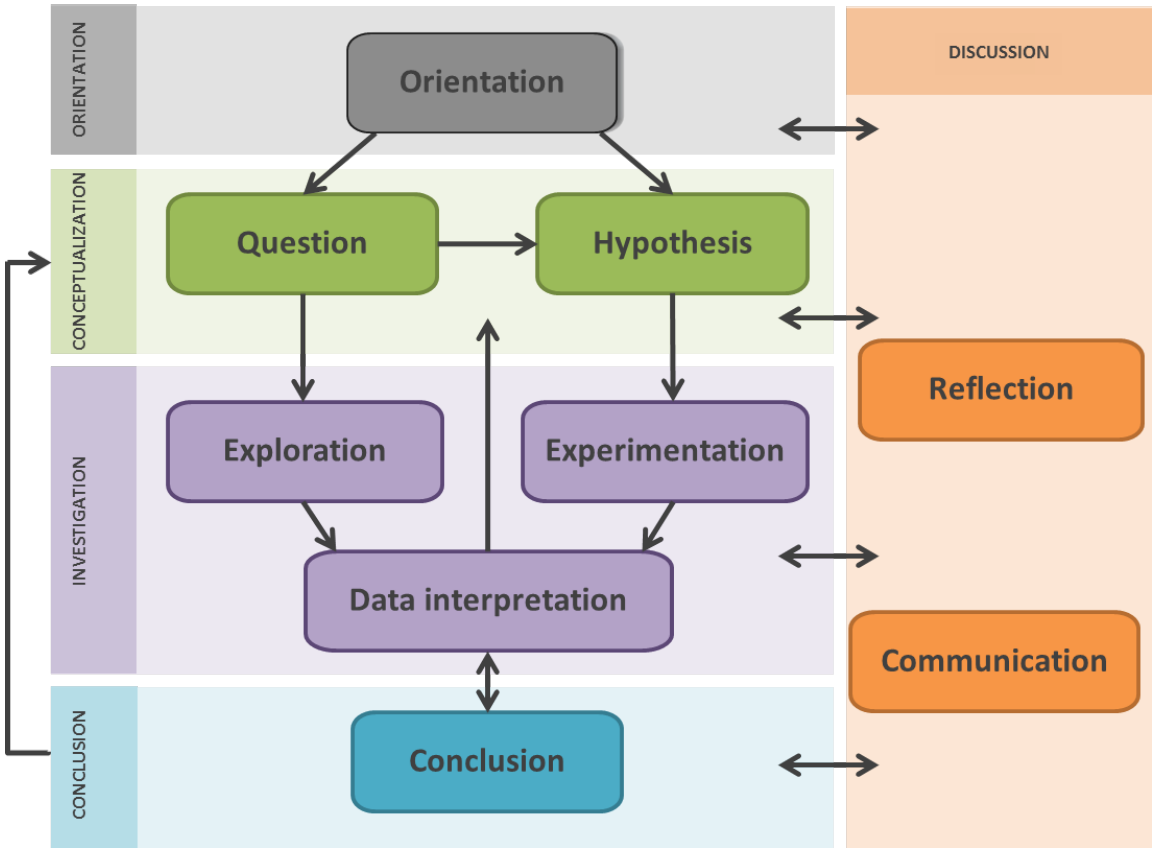
How to make inquiry learning effective?

- Open inquiry (discovery) doesn't work
- Students need support (guided inquiry):
  - By providing students with an overall strategy (inquiry cycle)
  - By giving students the right level of control
  - By ensuring the right level of prior knowledge
  - By providing students with guidance, e.g., scaffolds (apps)

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? *American Psychologist*, *59*, 14-19.

Riah, H., & Fraser, B. J. (1998, April). *Chemistry learning environment and its association with students' achievement in chemistry*. In annual meeting of the American Educational Research Association, San Diego, CA.

The Go-Lab inquiry cycle



Pedaste, M. Mäeots, M. Siiman L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zachariac, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: definitions and the inquiry cycle. *Educational Research Review*, *14*, 47-61.

Levels of inquiry

	Traditional Hands-on	Structured Inquiry	Guided Inquiry	Student directed Inquiry	Student research inquiry
Topic	Teacher	Teacher	Teacher	Teacher	Student
Question	Teacher	Teacher	Teacher	Teacher/ Student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedures/ design	Teacher	Teacher	Teacher/ Student	Student	Student
Results/ analysis	Teacher	Teacher/ Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student

Bonnstetter, R. J. (1998). Inquiry: learning from the past with an eye on the future. *Electronic Journal of Science Education*, *3* (1).

Aligning with prior knowledge

- Programs that promote deep learning programs (e.g., problem-based learning, inquiry learning) give low effect sizes if they are not preceded by surface learning (Hattie & Donoghue, 2016).
- A moderator analysis shows that simulations are only effective if preceded by instruction of the relevant concepts (Schneider & Preckel, 2017).

Hattie, J. A. C., & Donoghue, G. M. (2016). Learning strategies: a synthesis and conceptual model. *Npj Science Of Learning*, *1*, 16013.

Schneider, M., & Preckel, F. (2017). Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological Bulletin*, *143*, 565-600.

Sequencing inquiry and instruction

Genetics: students take the role of a plant or animal breeder and solve breeding problems

A. Classroom instruction before simulation

B. Classroom instruction after simulation

C. No simulation

B > A = C

Brant, G., Hooper, E., & Sugrue, B. (1991). Which comes first, the simulation or the lecture?, *Journal of Educational Computing Research, 7*, 469-481.

***My Money* game math skills**

A. Study before play

B. Study after play

C. Play only

A > B = C

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education*, *70*, 65-79.

Inquiry environment (wet lab) on magnetism

A. Information before lab

B. Information after lab

C. No information

Immediate effect: A = B > C

Long term effect: A > B= C

Wecker, C., Rachel, A., Heran-Dörr, E., Waltner, C., Wiesner, H., & Fischer, F. (2013). Presenting theoretical ideas prior to inquiry activities fosters theory-level knowledge. *Journal of Research in Science Teaching*, *50*, 1180-1206.

Concurrent inquiry and instruction

- Fictitious domain, shoe selling shop, so no prior knowledge
- Three conditions
  A. Information before simulation
  B. Information before simulation and during
  C. No information
- B > A > C
- B and A more hypothesis driven behavior

Lazonder, A. W., Hagemans, M. G., & de Jong, T. (2010). Offering and discovering domain information in simulation-based inquiry learning. *Learning and Instruction*, *20*, 511-520.

Never go beyond the ZPD

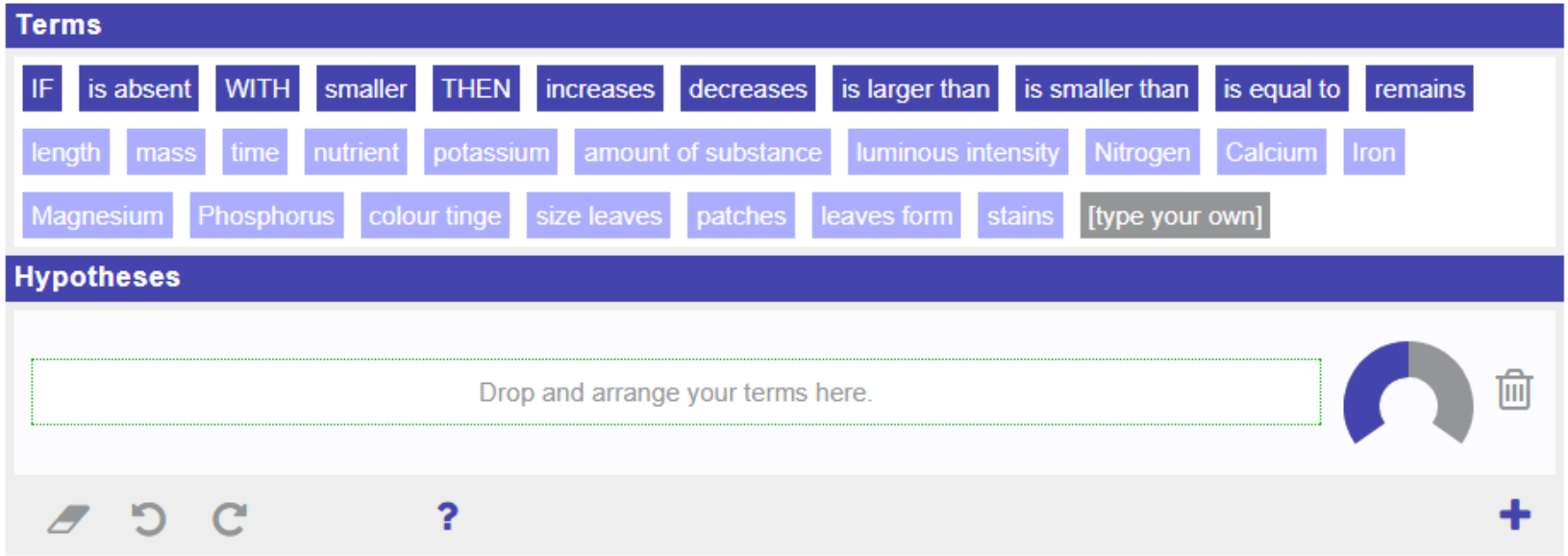
- Comparison of
  - Low prior knowledge students who learn much (LH)
  - Low prior knowledge students who do not learn that much (LL)
- PhET electrical circuit simulation
- LH students use more pauses to reflect on their experiments
- LH students choose electrical circuits that are less complex, clearly staying within their possibilities (Zone of Proximal Development)

Perez, S., Massey-Allard, J., Butler, D., Ives, J., Bonn, D., Yee, N., & Roll, I. (2017). Identifying productive inquiry in virtual labs using sequence mining. In E. André, R. Baker, X. Hu, M. M. T. Rodrigo, & B. du Boulay (Eds.), *Artificial intelligence in education: 18th international conference, AIED 2017, Wuhan, China, June 28 – July 1, 2017, proceedings* (pp. 287-298). Cham: Springer International Publishing.

Modern guided inquiry with scaffolds (tools/apps)

- Mixed and dynamic initiative
- Geared towards specific difficulties that students experience
- Possibility of fading

An example: the hypothesis scratchpad



- Domain terms provide content
- Conditionals help to formulate a testable hypothesis

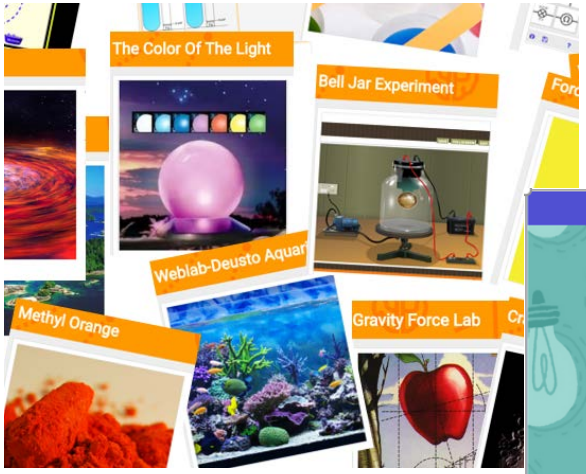
Based on: van Joolingen, W. R. & de Jong, T. (1991). Supporting hypothesis generation by learners exploring an interactive computer simulation. *Instructional Science*, *20*, 389-404.

nextlab

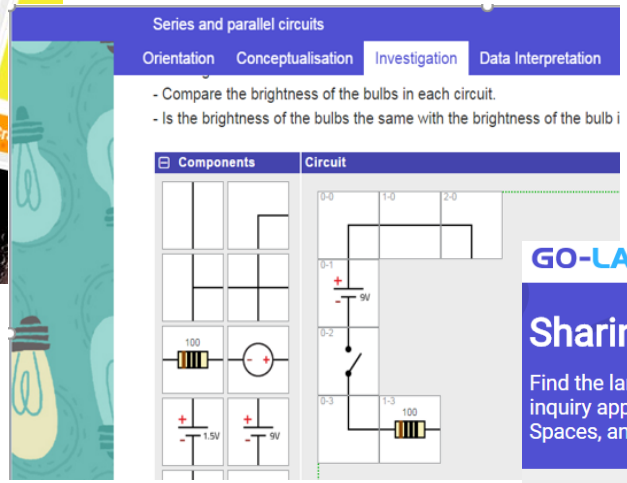
The Go-Lab ecosystem

Go-Lab in one slide

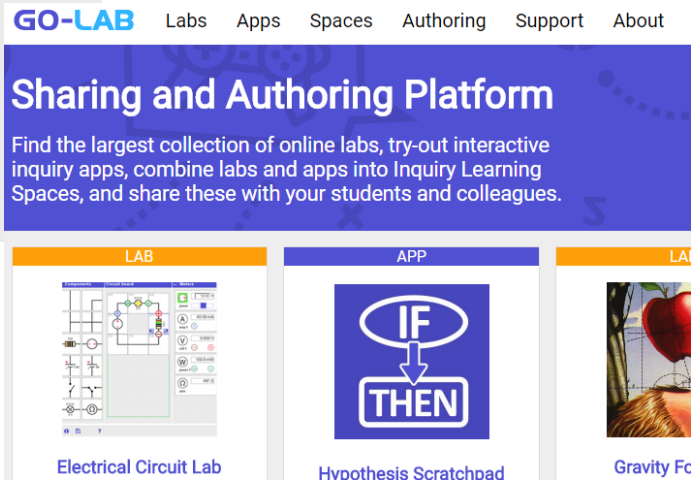
Federation of online labs ….



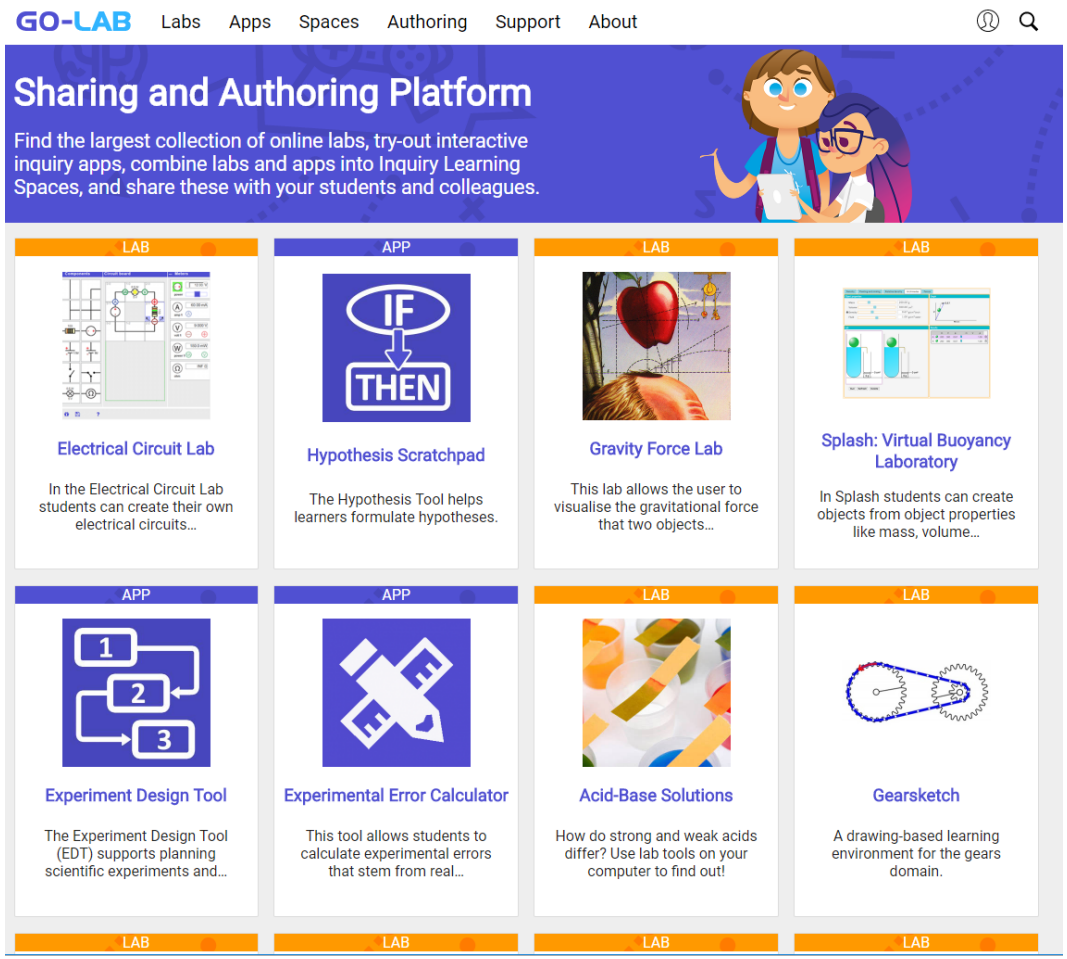
…. Embedded into educational resources and guidance ….



.. Shared with the community of users



Go-Lab sharing platform (www.golabz.eu)



What makes the Go-Lab ecosystem unique?

- It collects online labs from around the world in one portal
- Teachers can combine each lab with texts, videos, and apps (scaffolds) in structured learning environments and very easily adapt these to their own needs
- These learning environments can be distributed to students with one click of the button
- And they can be directly shared with other teachers who can re-use them by copying and adapting
- And much much more …

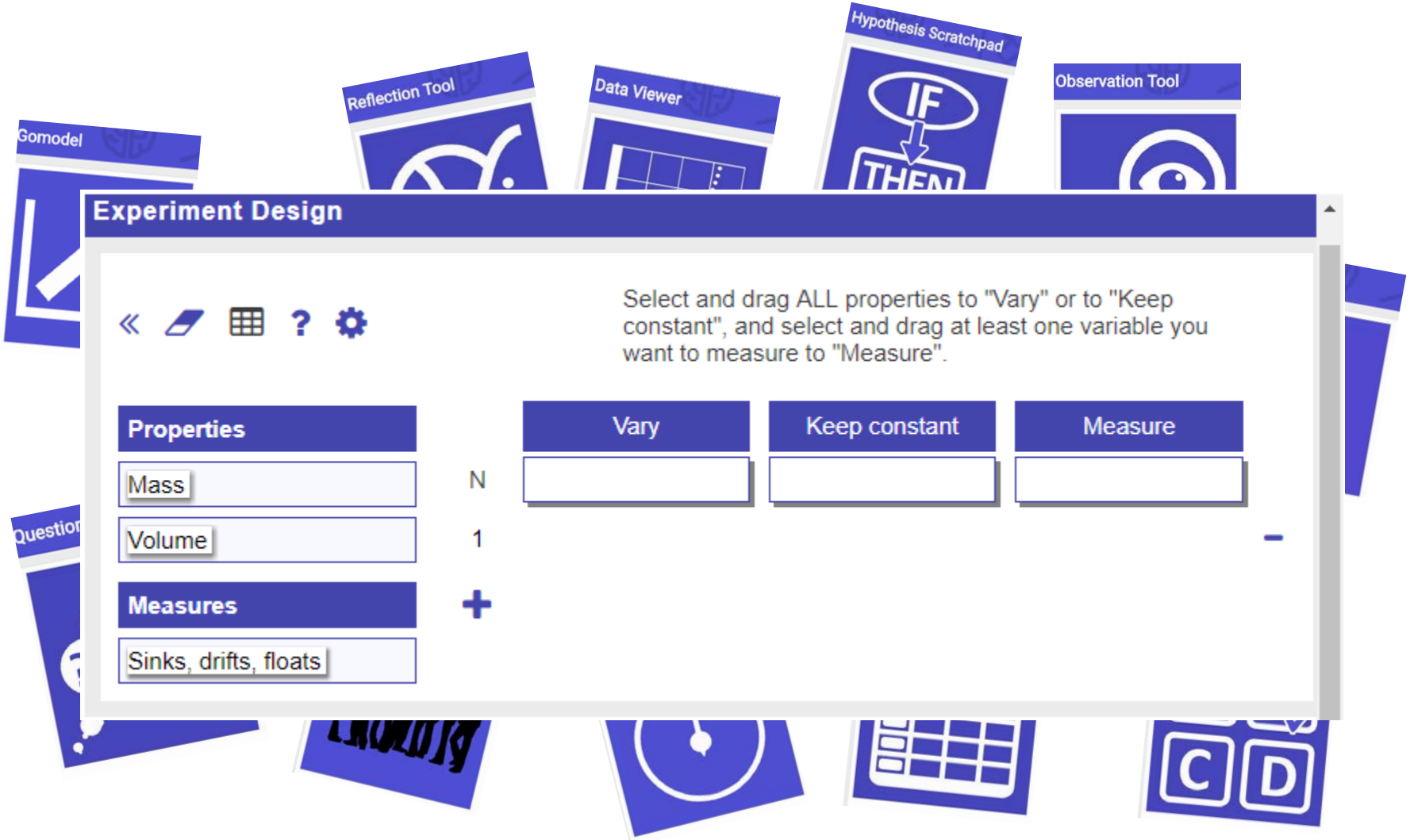
Is Go-Lab a success?

- Sharing platform
  - > 500 online labs
  - > 700 published learning spaces
  - 42 apps
- Over 200.000 different visitors
- 14:000 visits per month
- > 20.000 registrations authoring platform
- > 10.000 individuals developed a learning space

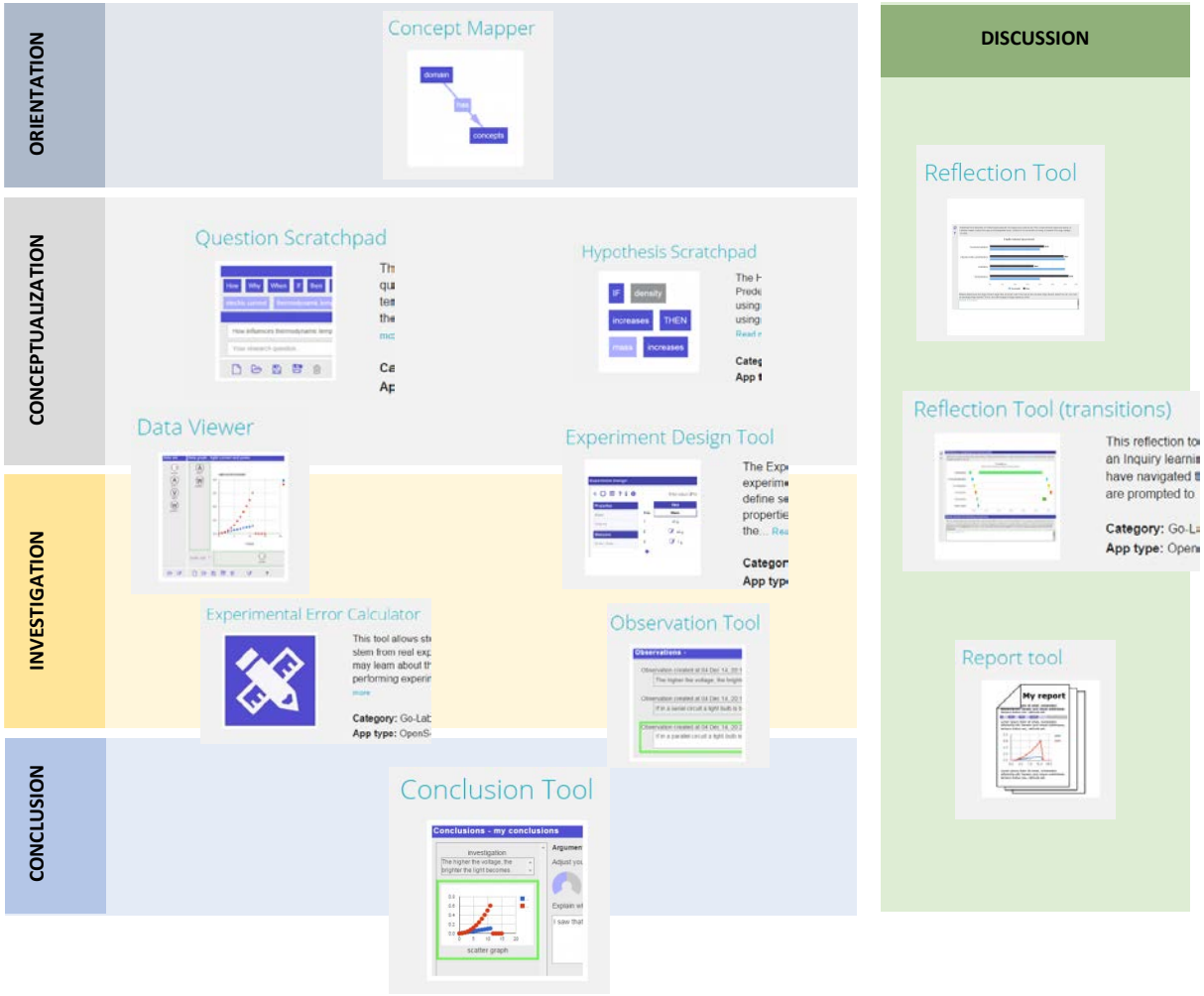
www.golabz.eu (520 labs)

www.golabz.eu (42 apps)

nextlab



An app for every phase



www.golabz.eu (743 inquiry spaces)

nextlab

21st century skills

Collaboration

The professional of the future

- T-shaped professional
- Wikipedia:

"The concept of **T-shaped skills**, or **T-shaped persons** is a metaphor used in job recruitment to describe the abilities of persons in the workforce. The vertical bar on the *T* represents the depth of related skills and expertise in a single field, whereas the horizontal bar is the ability to collaborate across disciplines with experts in other areas and to apply knowledge in areas of expertise other than one's own."

Example: collaboration - Tw1st education

- Knowledge about electricity transport for vocational students
- Shared lab on electricity transport, chat, role division
- RIDE rules
- Collaboration app:
  - Collaboration charting tool
  - Collaboration assessment tool
  - Evaluation, future actions

The Tw1st Education project is sponsored by NWO and Tech Your Future as project 409-15-209 and is a collaborative project between the University of Twente, Saxion University of Applied Sciences and four schools for Vocational training. The UT researchers are Elise Eshuis, Judith ter Vrugte, Anjo Anjewierden and Ton de Jong

twist education
Twenty-first century Skills for Technical Education

nextlab

Tw1st: Electricity transport lab

21stC Learning goal: the RIDE rules

RIDE Rule	Sub-rules
(R) Respect	Everyone will have a chance to contribute
	Everyone's ideas will be thoroughly considered
(I) Intelligent collaboration	Sharing all relevant information and suggestions
	Clarify the information given
	Explain the answers given
	Give criticism
(D) Deciding together	Explicit and joint agreement will precede decisions and actions
	Accepting that the group (rather than an individual member) is responsible for decisions and actions
(E) Encouraging	Ask for explanations
	Ask till you understand
	Give positive feedback

- Separate instruction before the lab
- Through the collaboration app

From: Saab, N., van Joolingen, W., & van Hout-Wolters, B. (2012). Support of the collaborative inquiry learning process: influence of support on task and team regulation. *Metacognition and Learning*, *7*, 7-23. (p. 13)

twist education
Twenty-first century Skills for Technical Education

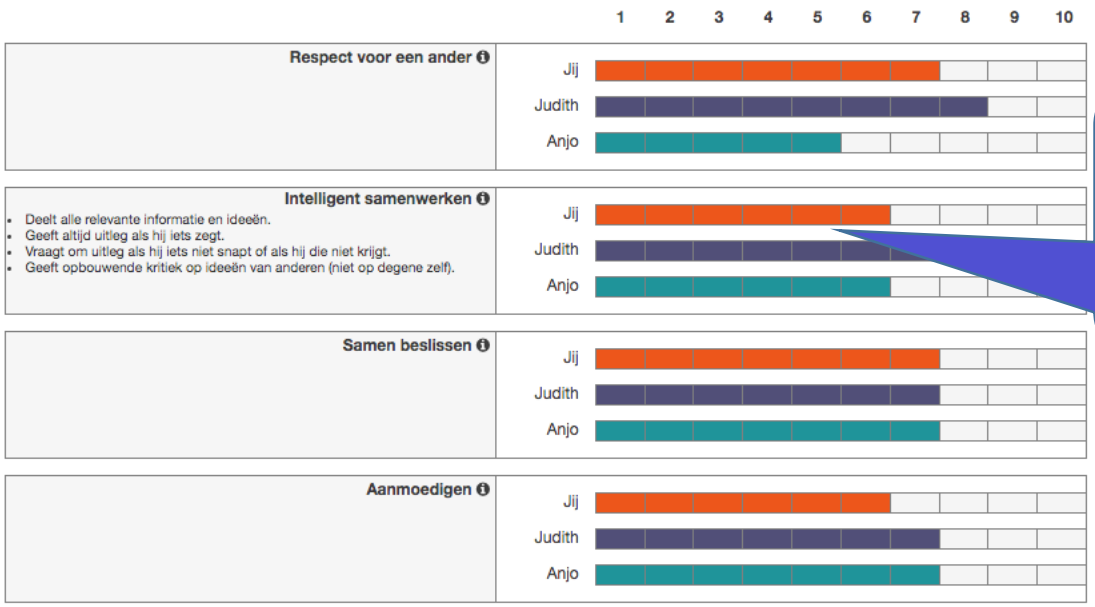
nextlab

Awareness: charting the collaboration

Wat moet je doen?

Geef **individueel** op een schaal van 1 tot 10 jezelf en de andere groepsleden een cijfer voor elke RISA regel (1 = alles kan beter, 10 = alles is perfect).
Klik op ℹ voor informatie.

Beoordeling samenwerking



Klaar

Judith is klaar | Anjo is klaar

Judge yourself and the others on the four RIDE rules

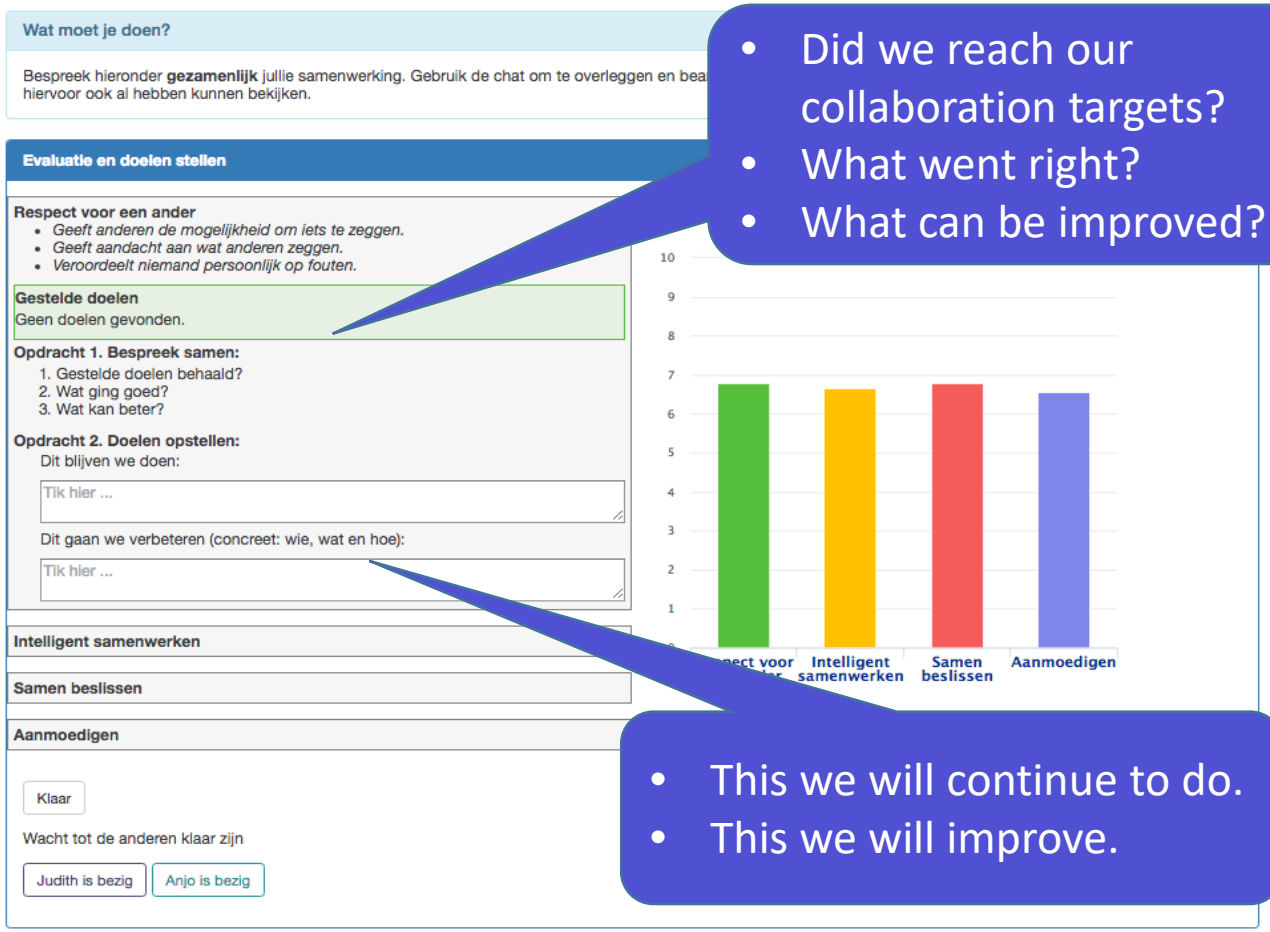
Awareness: Visualizing the collaboration

Overview per member of their own score and the average score by others about them, for each RIDE rule

twist education
Twenty-first century Skills for Technical Education

nextlab

Assessment – Lessons learned



- Did we reach our collaboration targets?
- What went right?
- What can be improved?

- This we will continue to do.
- This we will improve.

nextlab

21st century skills

Reflection

Reflection/critical thinking

- Reflection is a process "in which people recapture their experience, think about it, mull it over and evaluate it"
  - Boud D, Keogh R, Walker D. Reflection: turning experience into learning. London: Kogan Page; 1985. Promoting reflection in learning: a model; pp. 18–40.

- Reflection components
  - Awareness: product or process
  - Comparison to a norm (of expert, peers, theory)
  - Guiding questions

Reflection can be associated with learning

- Comparison of
  - Low prior knowledge students who learn much (LH)
  - Low prior knowledge students who do not learn that much (LL)
- PhET electrical circuit simulation
- LH students use more pauses to reflect on their experiments

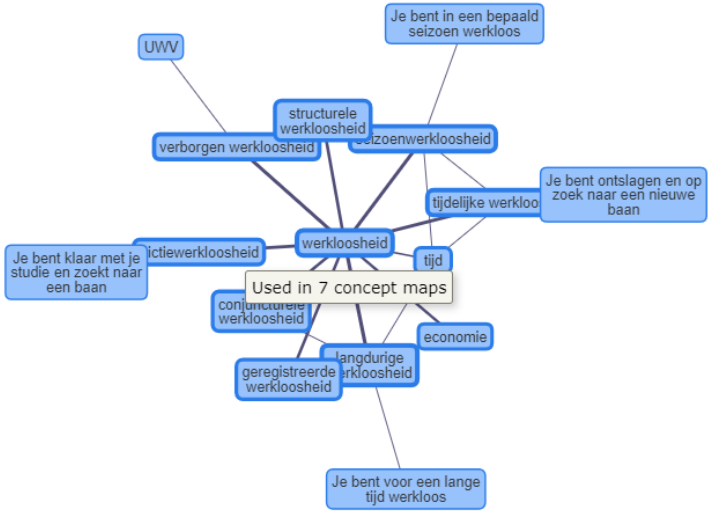
See also:

Fratamico, L., Conati, C., Kardan, S., & Roll, I. (2017). Applying a framework for student modeling in exploratory learning environments: Comparing data representation granularity to handle environment complexity. *International Journal of Artificial Intelligence in Education, 27*, 320-352.

Bumbacher, E., Salehi, S., Wierzchula, M., & Blikstein, P. (2015). Learning environments and inquiry behaviors in science inquiry learning: How their interplay affects the development of conceptual understanding in physics. In O. C. Santos, J. G. Boticario, C. Romero, M. Pechenizkiy, A. Merceron, P. Mitros, J. M. Luna, C. Mihaescu, P. Moreno, A. Hershkovitz, S. Ventura, & M. Desmarais (Eds.), *Proceedings of the 8th international conference on educational data mining* (pp. 61-69). Madrid.

Aggregated concept map - awareness

Aggregated concept map

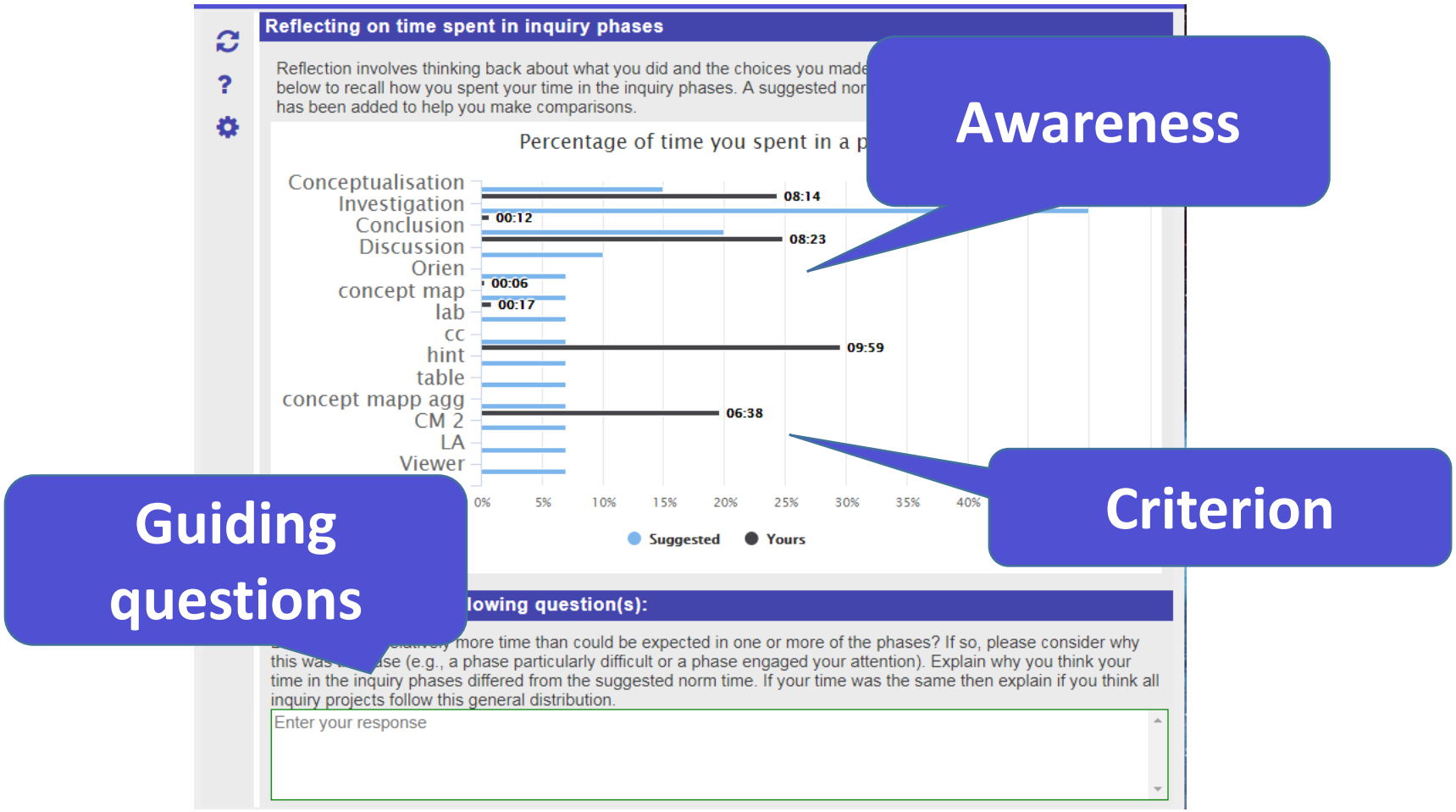


For every concept it is given in how many individual concept maps it appears. The thickness of the relations indicates how often this relation occurs.

Aggregated concept map - assessment

- Comparison with the ACM
  - Which concepts in your CM are missing compared to the ACM?
  - Are the concepts you can remove compared to the ACM?
  - Etc.
- Application of general rules
  - Can you make the concept map simpler without losing explanation power?
  - Can you group concepts at the same level of abstraction?
  - Etc.

App: Reflection over time spent



nextlab

Is inquiry learning effective?

Is inquiry learning effective?

- On the basis of meta-analyses: yes
  - Compared to direct instruction better results of inquiry learning
    - But only when guidance is offered
    - If introduced after surface learning

- Comment:
  - Only studies with a significant result are published

de Jong, T. (2006). Computer simulations - Technological advances in inquiry learning. *Science*, *312*, 532-533.

de Jong, T., Linn, M.C., & Zacharia, Z.C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*, 305-308

Hattie, J. A. C., & Donoghue, G. M. (2016). Learning strategies: A synthesis and conceptual model. *Npj Science Of Learning, 1*, 16013.

Is inquiry learning effective?

- On the basis of PISA data: no
  - PISA data show a negative correlation between exposure to inquiry and scores in science

- Comment:
  - Based on student reporting
  - Teacher/course quality is not measured
  - May often refer to traditional recipe like practicals
  - Data concerns frequency

OECD. (2016). *Pisa 2015 results (volume II): Policies and practices for successful schools,* . Paris (France): PISA, OECD Publishing.
Cairns, D., & Areepattamannil, S. (in press). Exploring the relations of inquiry-based teaching to science achievement and dispositions in 54 countries. *Research in Science Education*.

Conclusion – a balanced curriculum

- Inquiry learning (with online labs) may help to improve students' conceptual knowledge
- Should be embedded in (teacher – peer – software) guidance
- Should be at the right place in the curriculum (after acquiring surface knowledge)
- Should be used to a certain frequency level
- Teachers should receive an adequate (in/pre-service training on pedagogy and technology)

GO-LAB

www.golabz.eu