An Introduction to Intelligent Tutoring Systems (ITS)

(a.k.a. cyber-tutoring, digital tutors, ICAI)

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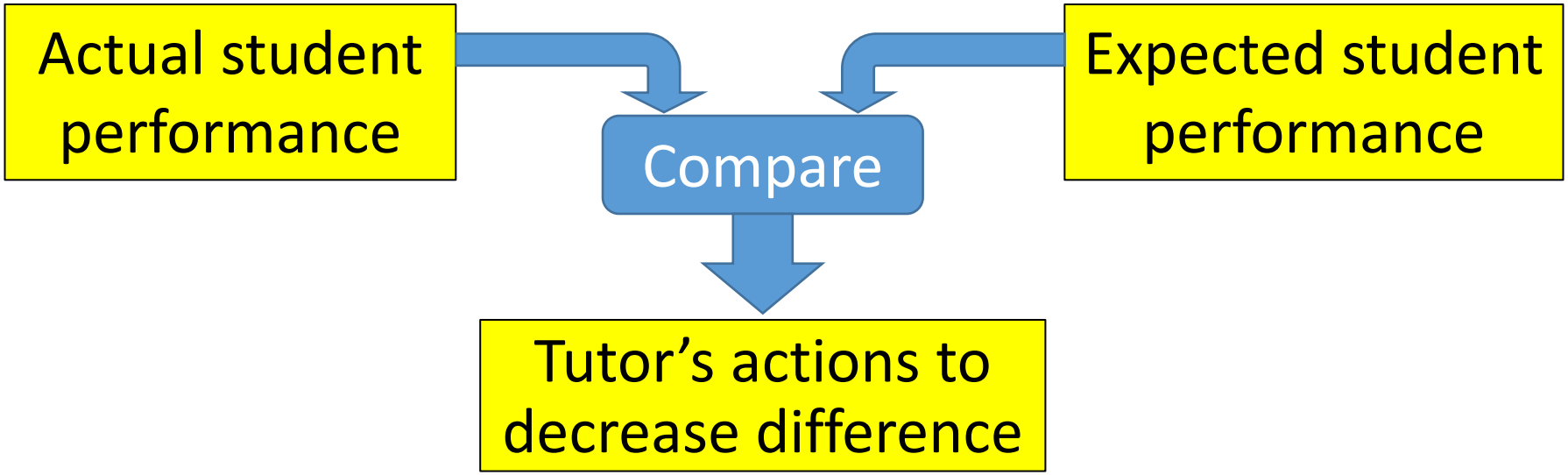
Soller et al. (2005) claim edutech innovation is either:

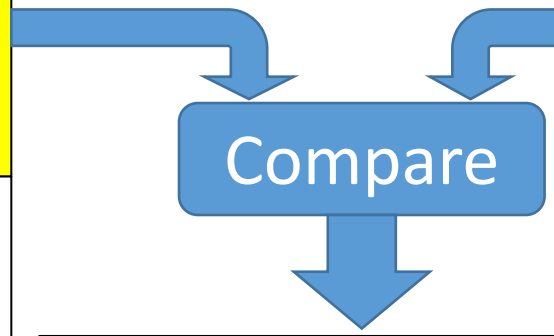
- **Structural:** Changes the lesson plan, content and activities
- **Regulative:** Adds a regulative (i.e., cybernetic; feedback) loop:
  - **Sense** the students' performance
  - **Compare** the students' performance to **Expectations**
  - **Act** to decrease Δ between the students' actual and expected performance

- Soller, A., Martinez, A., Jermann, P., & Muehlenbrock, M. (2005). From mirroring to guiding: A review of state of the art technology for supporting collaborative learning. *International Journal of Artificial Intelligence and Education, 15*, 261-290.
- VanLehn, K. (2016). Regulative loops, step loops and task loops. *International Journal of Artificial Intelligence in Education, 26*(1), 107-112

Main components of an ITS Viewed as a regulative loop



To design an ITS, choose at least one from each column



Actual student performance

Sources:

- ❑ Answers to questions
- ❑ Essays
- ❑ Actions in a game
- ❑ Etc.

Tutor's actions to decrease difference

Action types:

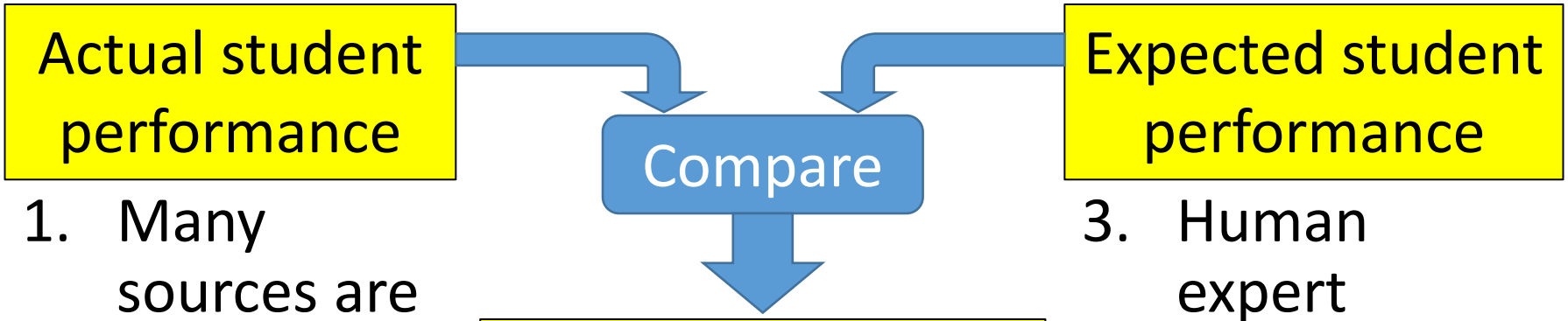
- ❑ Give feedback
- ❑ Choose next task
- ❑ Etc.

Expected student performance

Sources:

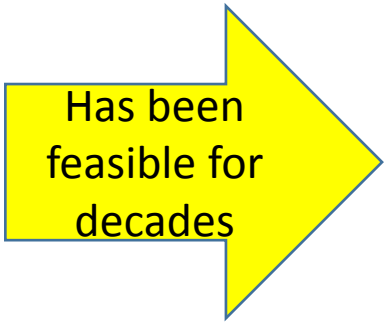
- ❑ Expert authors
- ❑ Algorithms
- ❑ Etc.

I will make 4 main points

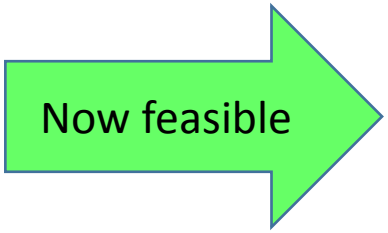


1. Many sources are feasible
2. More frequent data are better, up to a point.
3. Human expert authors are (still) the main source.
4. Only three tutor action types have strong evidence of effectiveness.

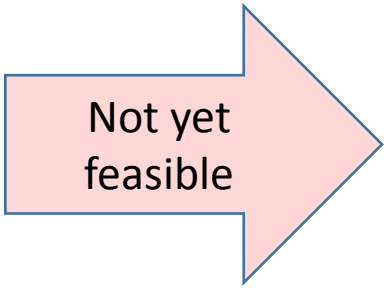
Main sources of student performance data



- Answer-based
  - Tutor assigns task, then student (eventually) enters a short answer e.g., multiple choice, number, drag & drop…

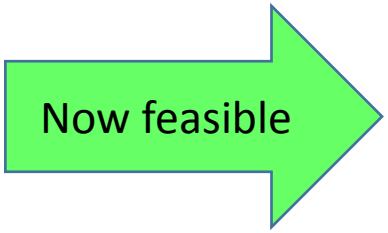


- Step-based
  - Tutor assigns task, then student makes many actions observed by the tutor (steps).



- Spoken student discussions
  - Tutor assigns task, then a small group of students discuss orally.

Next 7 slides are examples of step-based tutors' user interfaces



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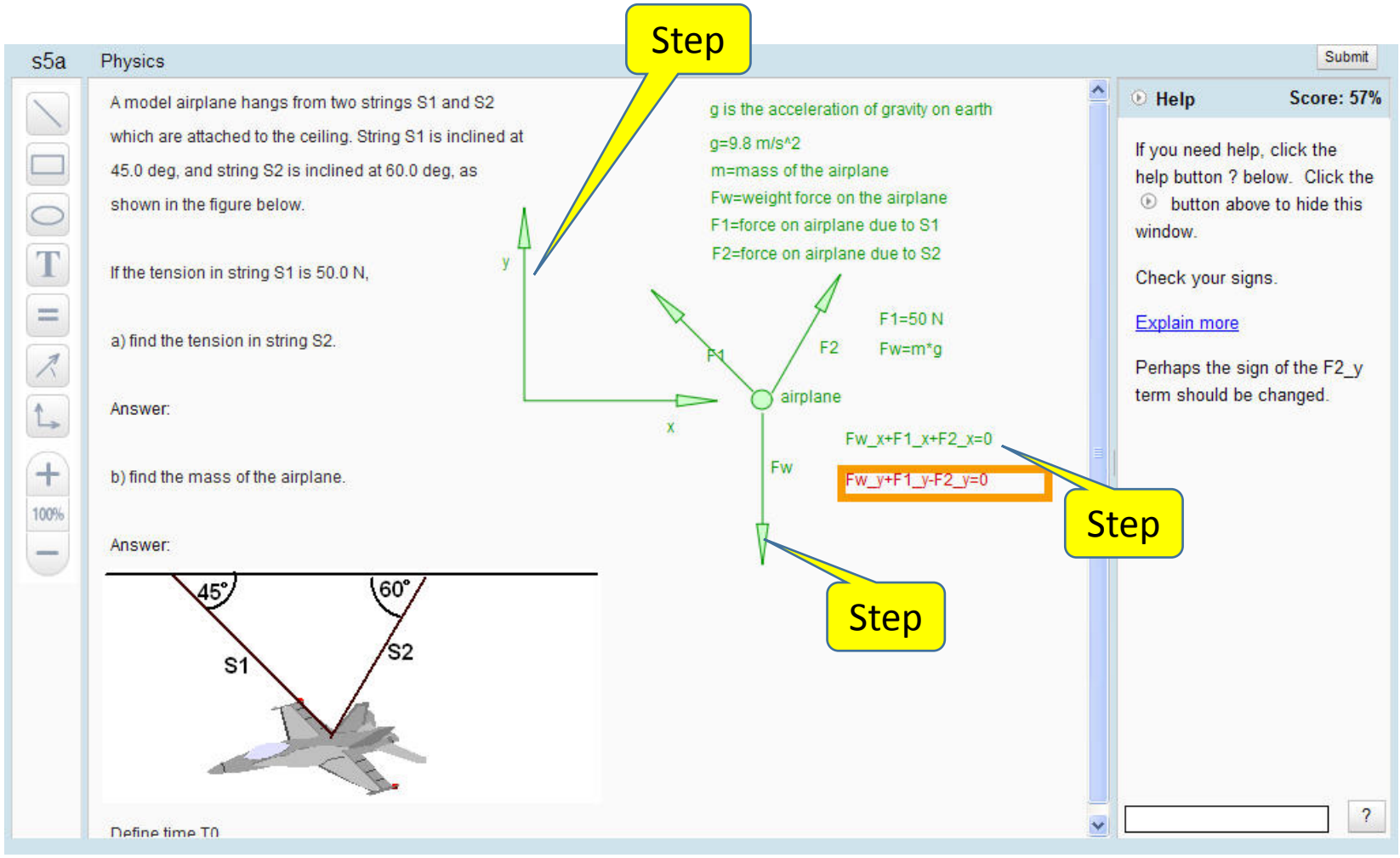
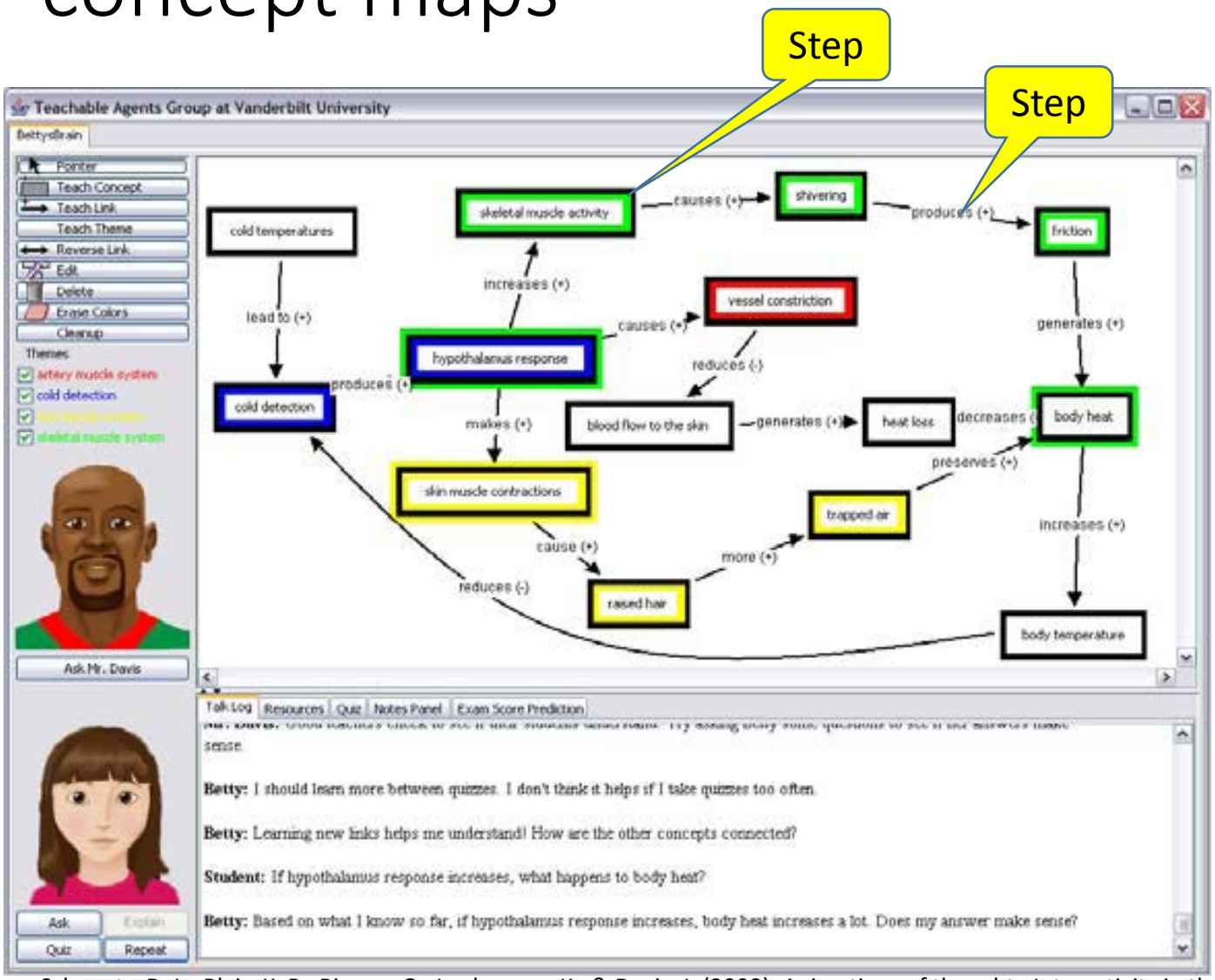
An editor for solving physics problems



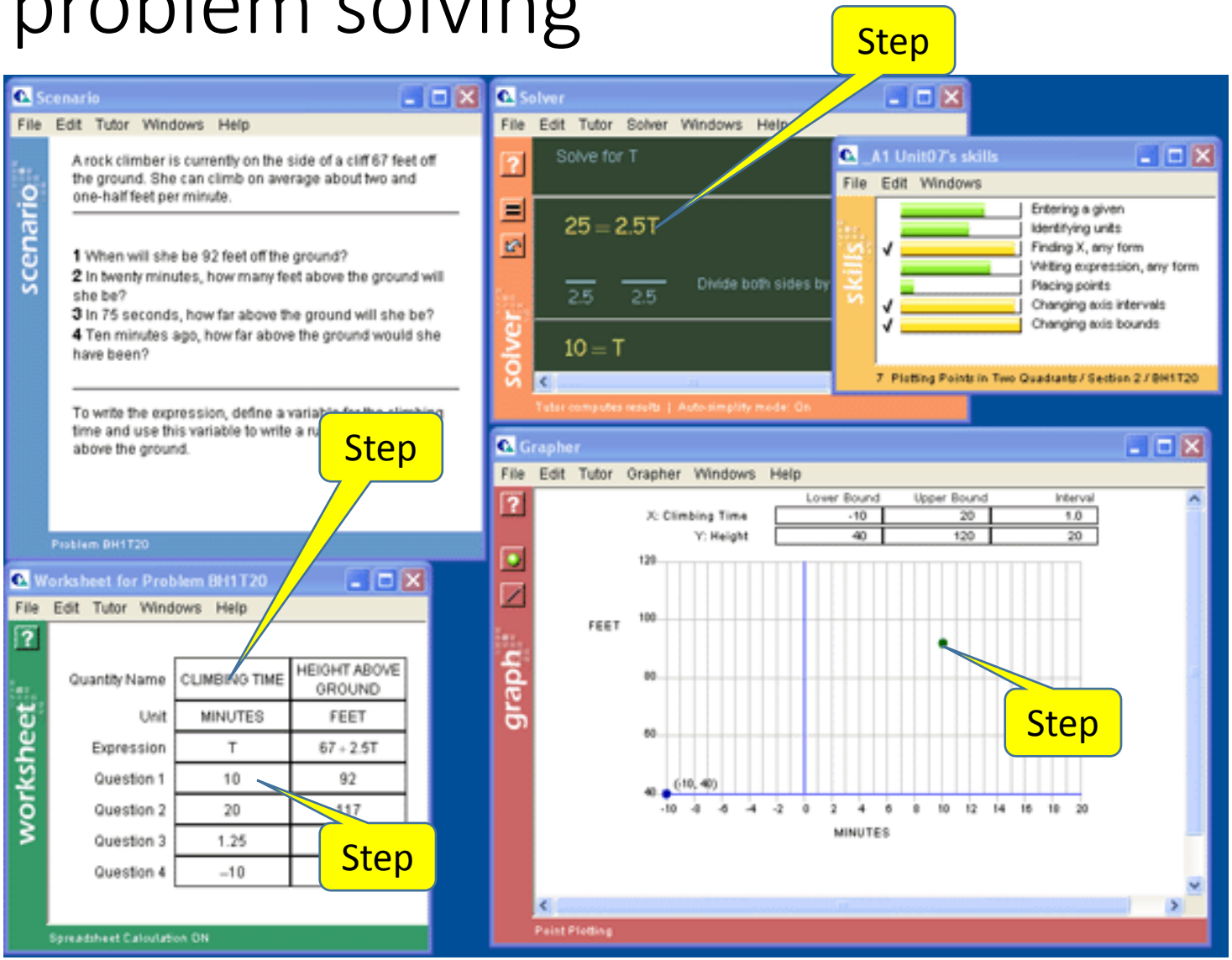
VanLehn, K., Lynch, C., Schultz, K., Shapiro, J. A., Shelby, R. H., Taylor, L., et al. (2005). The Andes physics tutoring system: Lessons learned. *International Journal of Artificial Intelligence and Education, 15(3), 147-204.*

An editor for constructing concept maps



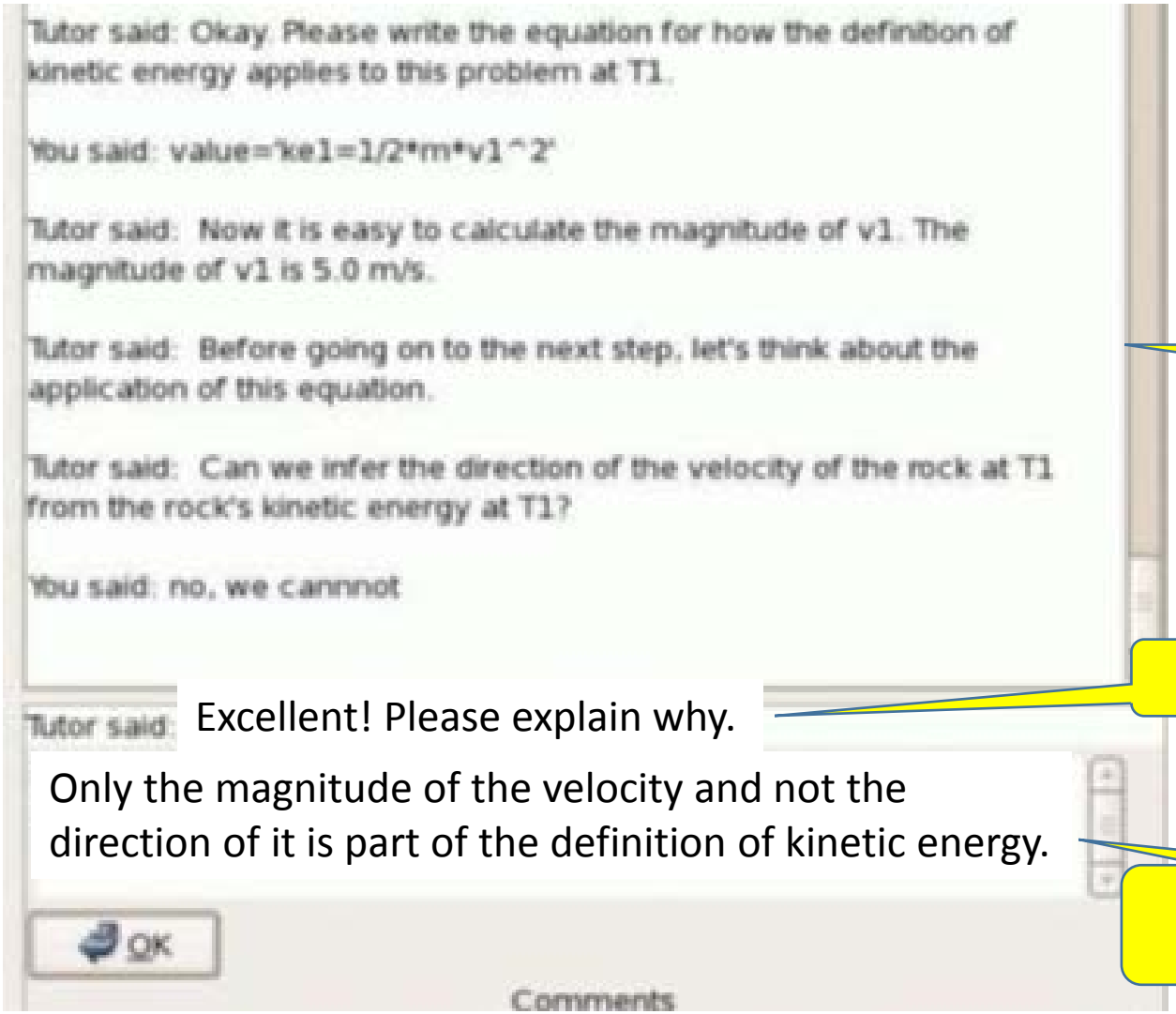
Schwartz, D. L., Blair, K. P., Biswas, G., Leelawong, K., & Davis, J. (2008). Animations of thought: Interactivity in the teachable agent paradigm. In R. Lowe & W. Schnotz (Eds.), *Learning with animations: Research and implications for design. Cambridge, UK: Cambridge University Press.*

An editor for complex math problem solving



www.carnegielearning.com

Tutor-student dialogue



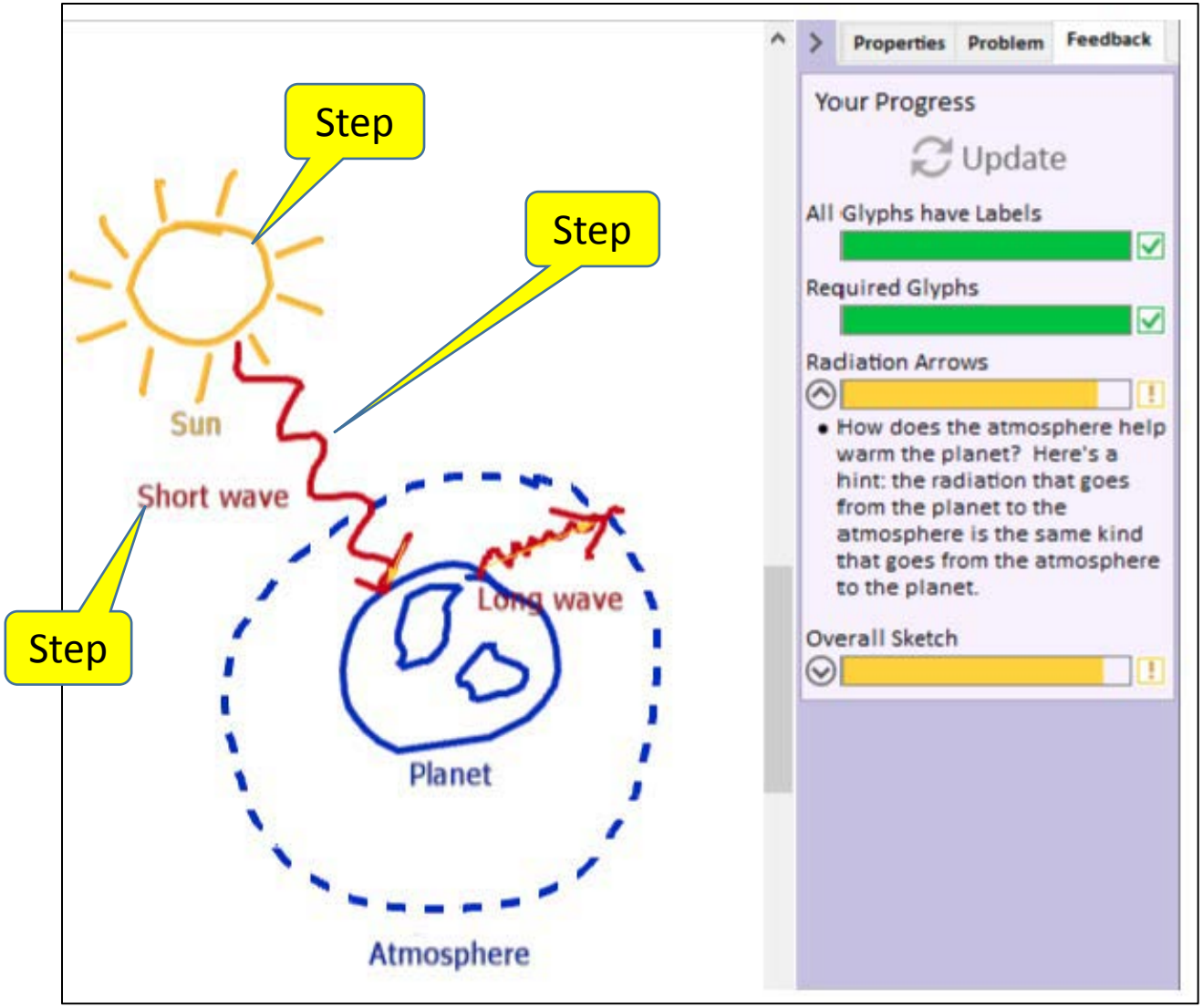
Past dialogue

Tutor's dialog turn

Step:
Student's dialog turn

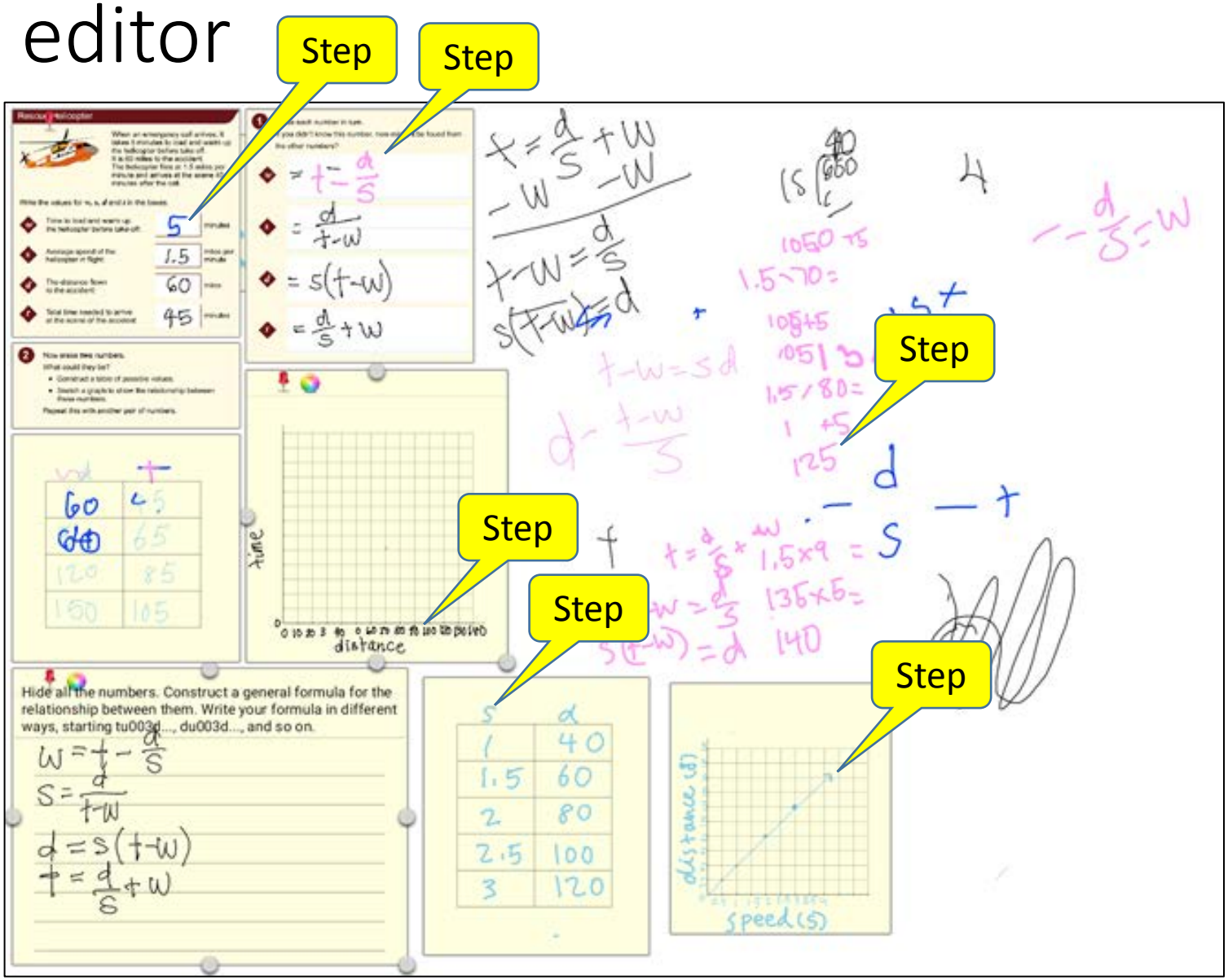
Chi, M., Jordan, P., & VanLehn, K. (2014). When is tutorial dialogue more effective than step-based tutoring? *International Conference on Intelligent Tutoring Systems* (pp. 210-219). Berlin: Springer.

An editor for drawing explanations



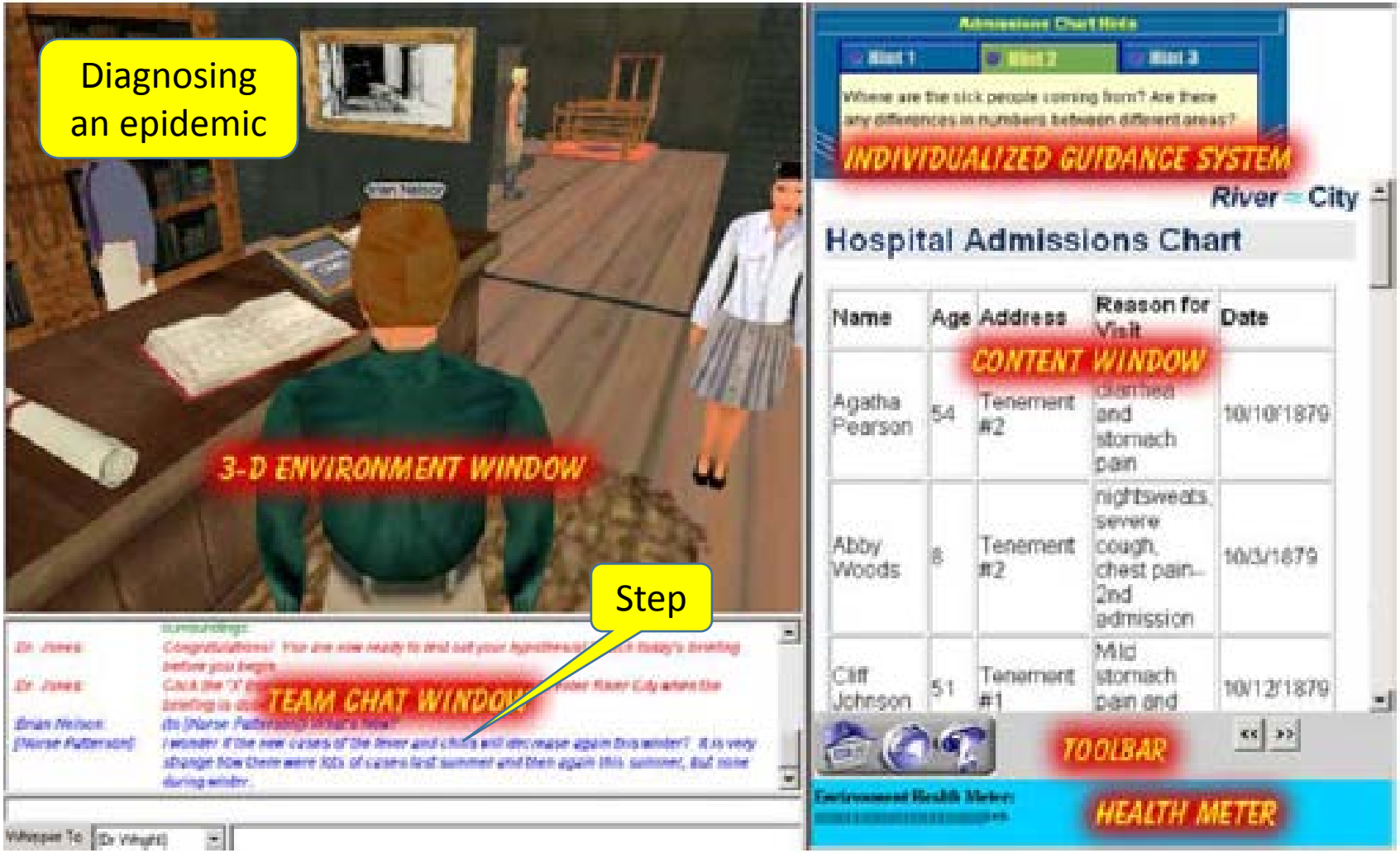
Forbus, K. D. (2016). Sketch understanding for education. In R. Sottilare, A. C. Graesser, X. Hu, A. Olney, B. d. Nye, & A. M. Sinatra (Eds.), Design Recommendations for Intelligent Tutoring Systems: Volume 4 Domain Modeling (pp. 225-235): US Army Research Laboratory.

A general-purpose collaborative editor



VanLehn, K., Burkhardt, H., Cheema, S., Pead, D., Schoenfeld, A. H., & Wetzel, J. (submitted). How can a classroom orchestration system help math teachers improve collaborative, productive struggle?

A multiplayer game



Nelson, B. C. (2007). Exploring the use of individualized, reflective guidance in an educational multi-user virtual environment. Journal of Science Education and Technology, 16(1), 83-97.

How close are tutors to understanding unconstrained speech?

Has been feasible for decades

- Answer-based
  - Tutor assigns task, then student (eventually) enters a short answer e.g., multiple choice, number, drag & drop…

Now feasible

- Step-based
  - Tutor assigns task, then student makes many actions observed by the tutor (steps).

Not yet feasible

- Spoken student discussions
  - Tutor assigns task, then a small group of students discuss orally.

Tutor's can understand constrained speech

Radio operator (RTO) practices calling for artillery fire

1. RTO: steel one niner this is gator niner one adjust fire polar over
2. FSO: gator nine one this is steel one nine adjust fire polar out
3. RTO: direction five niner four zero distance four eight zero over
4. FSO: direction five nine four zero distance four eight zero over

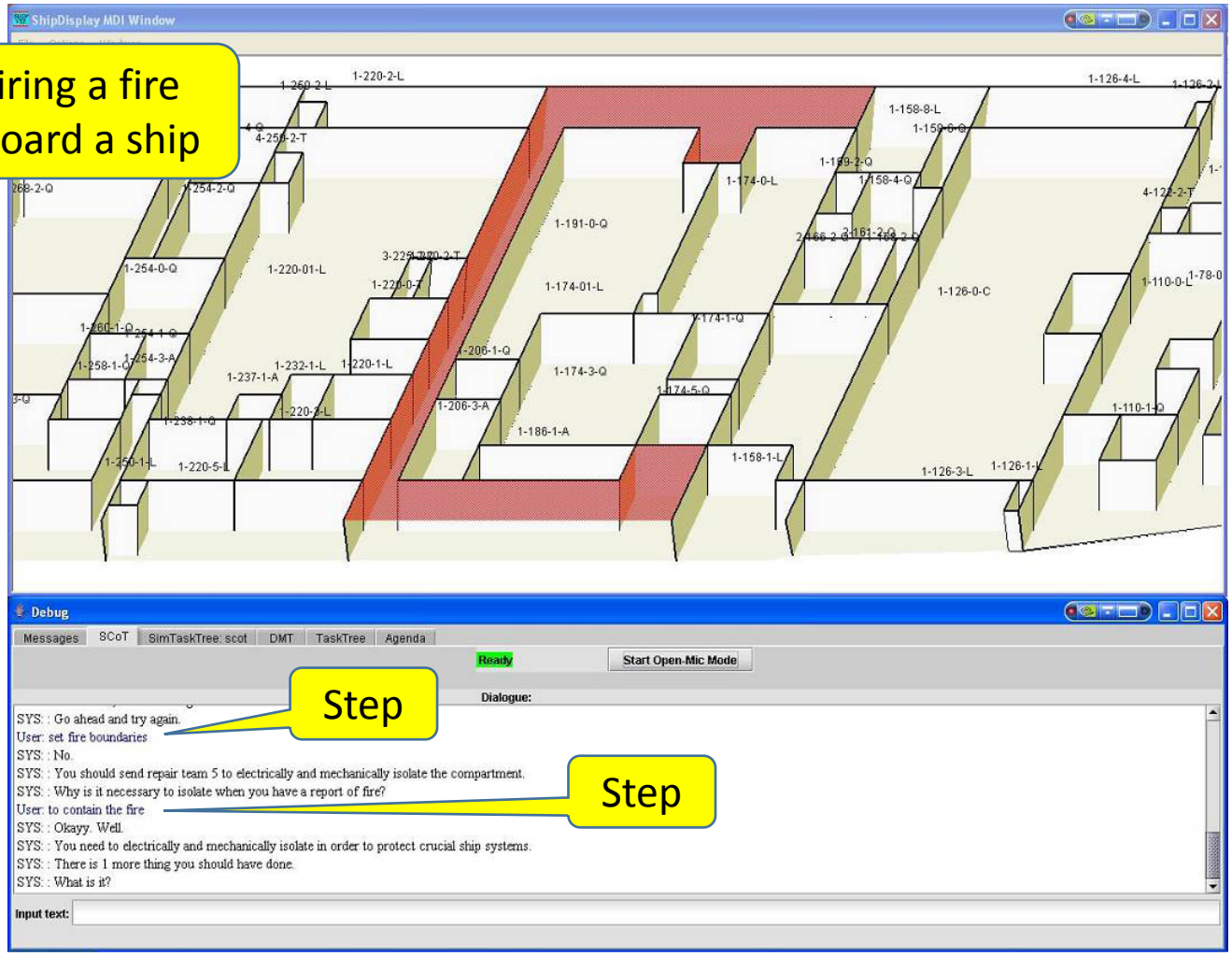
Step

Step

http://www.netc.navy.mil/centers/swos/Simulators.htm

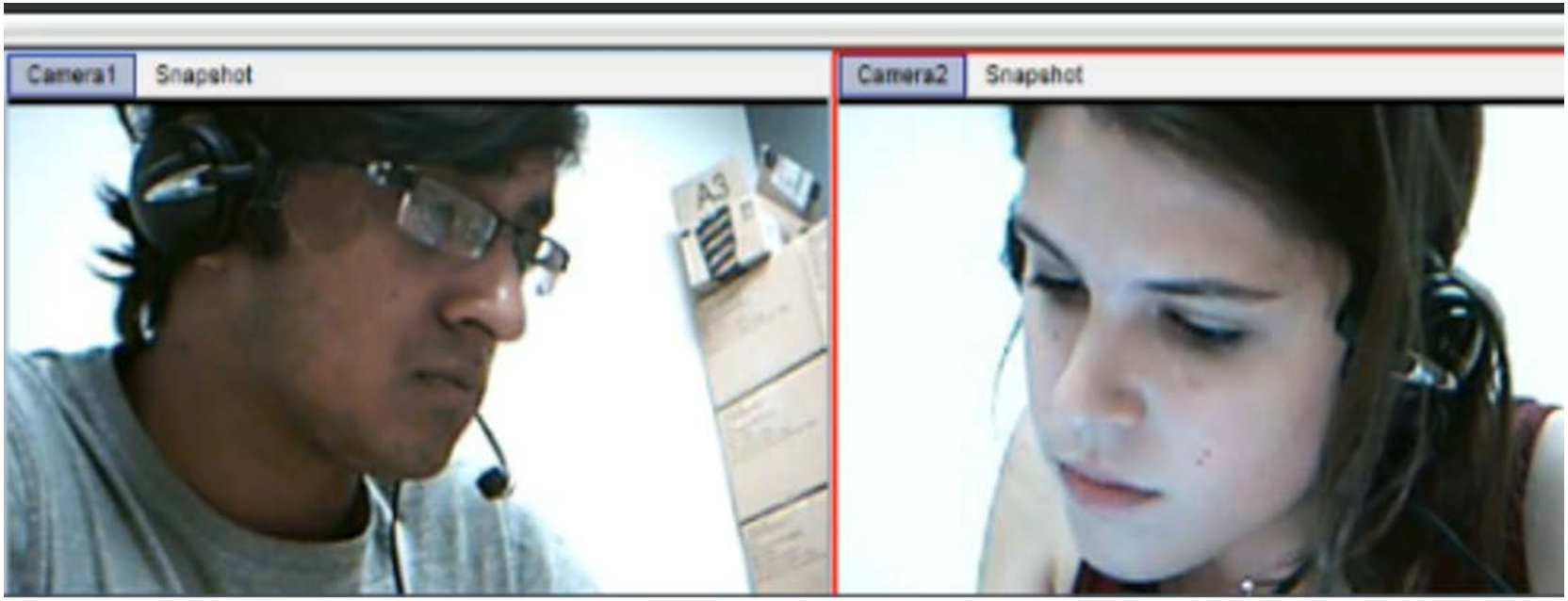
Tutors can understand short answers to their questions

Firing a fire aboard a ship



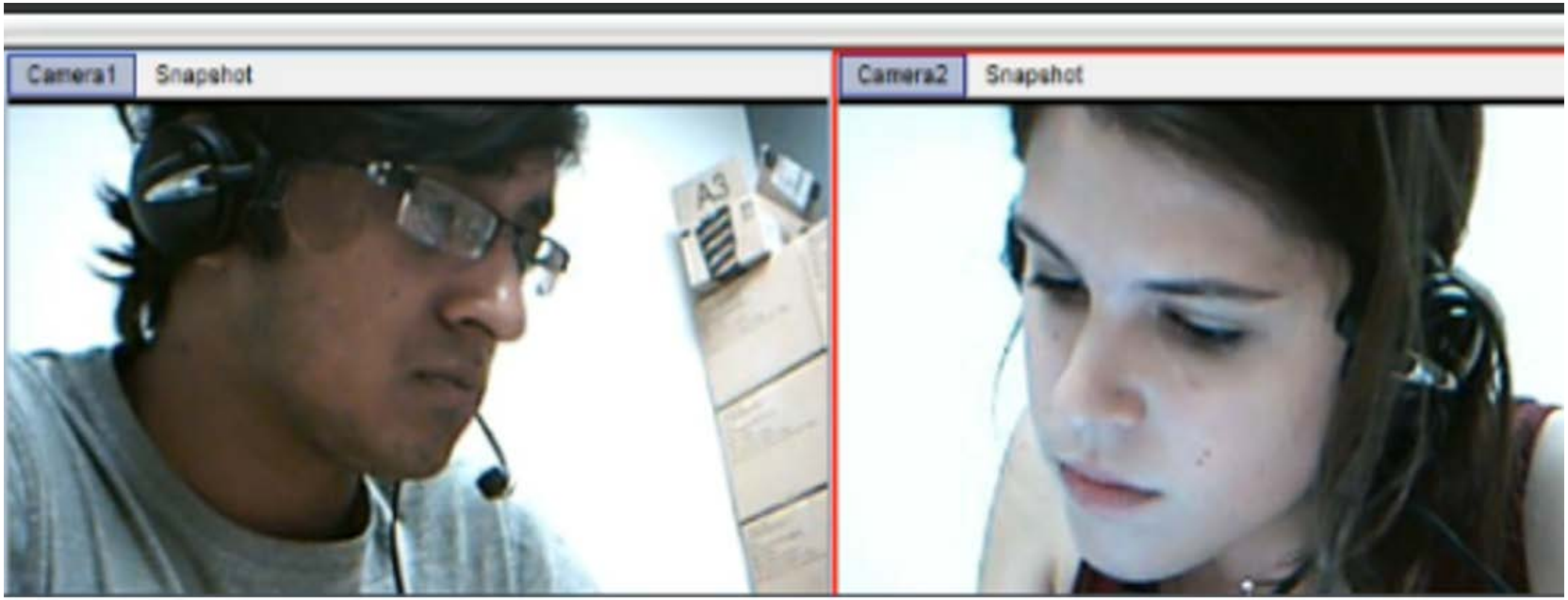
Pon-Barry, H., Schultz, K., Bratt, E. O., Clark, B., & Peters, S. (2006). Responding to student uncertainty in spoken tutorial dialogue systems. International Journal of Artificial Intelligence and Education, 16, 171-194.

Tutors can understand affect & collaboration in spoken conversations in lab settings

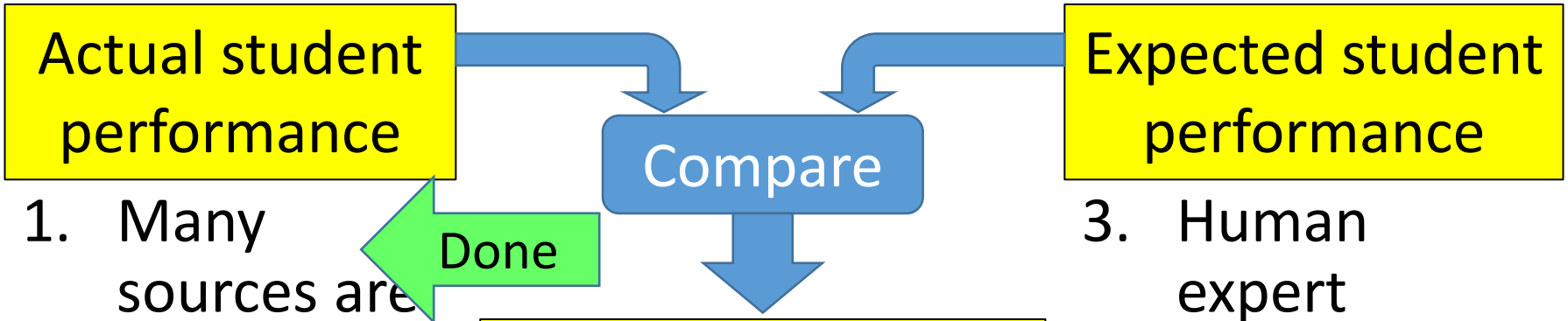


- Viswanathan, S. A., & VanLehn, K. (in press). Using the tablet gestures and speech of pairs of students to classify their collaboration. *IEEE Transactions on Learning Technologies*.
- Forbes-Riley, K., & Litman, D. (2014). Evaluating a spoken dialogue system that detects and adapts to user affective states. Paper presented at the *SIGDial: 15th Annual Meeting of the Special Interest Group on Discourse and Dialogue*, Philadelphia, PA.

Tutors **cannot yet** understand the content of unconstrained conversation between students, even in lab settings



Main points: Transition slide



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4. Only three tutor action types have strong evidence of effectiveness.

More frequent tutor-student interactions foster more learning, up to a point

Tutoring type	vs. other tutoring type	Num. of effects	Mean effect
Answer-based	no tutoring	165	0.31
Step-based		28	0.76
Human		10	0.79

- Answer-based > no tutoring by 0.30
- Step-based tutoring > answer-based by 0.45
- Human tutoring = step-based tutoring

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems and other tutoring systems. *Educational Psychologist, 46(4), 197-221*

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Step-based		28	0.76
Human		10	0.79
Step-based	answer-based	2	0.40
Human		1	-0.04
Human	step-based	10	0.21

- Answer-based > no tutoring by 0.30
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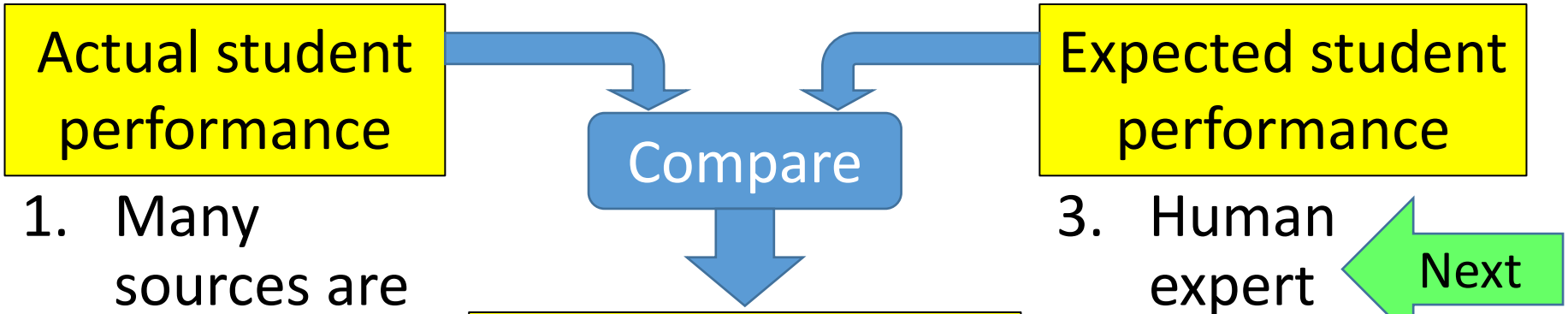

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2. More frequent data are better, up to a point.

Done

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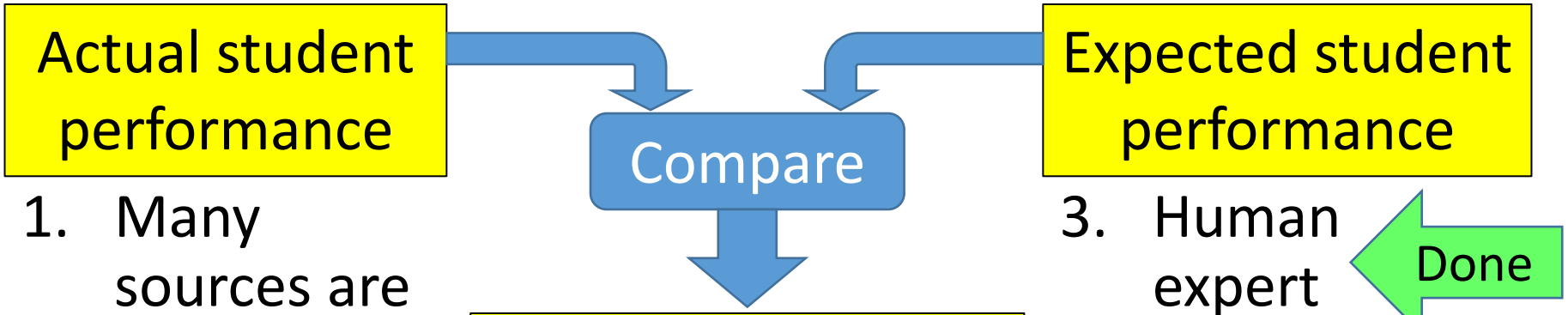
Next

Authoring:

- A human author invents the task
- Expected student performance on it = set of steps
  - Each step is marked as correct vs. incorrect
  - May also be marked for concepts & misconceptions
- Sources of expected performances (steps)
  - Human author performs the task in all ways
  - Students mark each other's performances
  - Algorithm performs the task in all ways
  - Human authors one performance; algorithm generates all equivalents
  - Algorithm clusters student performances; human marks the prototype of each cluster

Well-defined task domains only

Main points: Transition slide



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Next

Common activities in classes.

- Reading & watching videos
- Whole class lectures & discussions
- Assessments (i.e., tests)
- Individual practice
- Small group work
- Projects
- Field trips

Next

ITS are feasible

Strong evidence that adaptive assessment is more effective

- After the student enters the answer to a task
  - System updates its estimate of the student's mastery
  - System choose task that will maximize information gain
  - System present the task to the student
- Effectiveness
  - Validity – same as convention assessment
  - Reliability – same or better
  - Efficiency – better or same
- Widely used

Wainer, H., Dorans, N. J., Eignor, D., Flaugher, R., Green, B. F., Mislevy, R. J., . . . Thissen, D. (2000). Computerized adaptive testing: A primer (second ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Likely that embedded assessment is more effective

- The ITS updates estimates of student's competence as the student gets feedback, hints, etc.
  - Assessing a moving target
- Practical advantages
  - No time wasted on testing
  - No test anxiety
  - No make-up tests
  - No test security issues
- Effectiveness
  - Reliability – excellent, but not clear how to compare
  - Validity – few studies

Corbett, A., & Anderson, J. R. (1995). Knowledge tracing: Modeling the acquisition of procedural knowledge. *User Modeling and User-Adapted Interaction, 4*, 253-278.

Strong evidence that mastery learning increases learning

- Mastery learning (also called Gating)
  - *Conventional* assessment: If you fail the test at the end of the module, you must study the module again and try the test again.
  - *Embedded* assessment: Keeping doing tasks until the ITS says you can go to the next module.

- Many studies, with & without ITS
  - Across 108 studies, effect size = 0.52

Kulik, C., Kulik, J., & Bangert-Drowns, R. (1990). Effectiveness of mastery learning programs: A meta-analysis. *Review of Educational Research, 60*(2), 265-306.

Strong evidence that feedback & hints increase learning

- As mentioned earlier
  - Answer-based vs. no-tutoring: 0.31 effect size
  - Step-based vs. no-tutoring: 0.76
  - Human tutors vs. no-tutoring: 0.79

- Most recent meta-evaluations
  - Answer based (CAI) vs. baseline: 0.38
  - ITS vs. baseline: 0.66
  - Human tutors vs. baseline: 0.40

Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems: A meta-analytic review. *Review of Educational Research, 86*(1), 42-78.

Adaptive task selection: Weak evidence or effect

- Choose tasks to match the student's learning style
  - No evidence (yet) of effectiveness

Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. A. (2008). Learning styles: Concepts and evidence. *Psychological Science in the Public Interest, 9*(3), 105-119.

Adaptive task selection: Weak evidence or effect

- Choose tasks to match the student's learning style
  - No evidence (yet) of effectiveness
- Let the learner, not the system, choose tasks
  - Very small effect size

Karich, A. C., Burns, M. K., & Maki, K. E. (2014). Updated meta-analysis of learner control within educational technology. *Review of Educational Research, 84*(3), 392-410.

Adaptive task selection: Weak evidence or effect

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- Space repeated tasks far apart
  - Strong evidence but only for memorization

Sense, F., Behren, F., Meijer, R.B. & van Rijn, H. (2016) An individual's rate of forgetting is stable over time but differs across materials. *Topics in Cognitive Science*, 8(1), 305-321.

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- Space repeated tasks far apart
  - Strong evidence but only for memorization
- Task difficulty matches student's competence
  - No studies apart from mastery learning?
- Choose tasks with a few unmastered topics
  - Just one study?

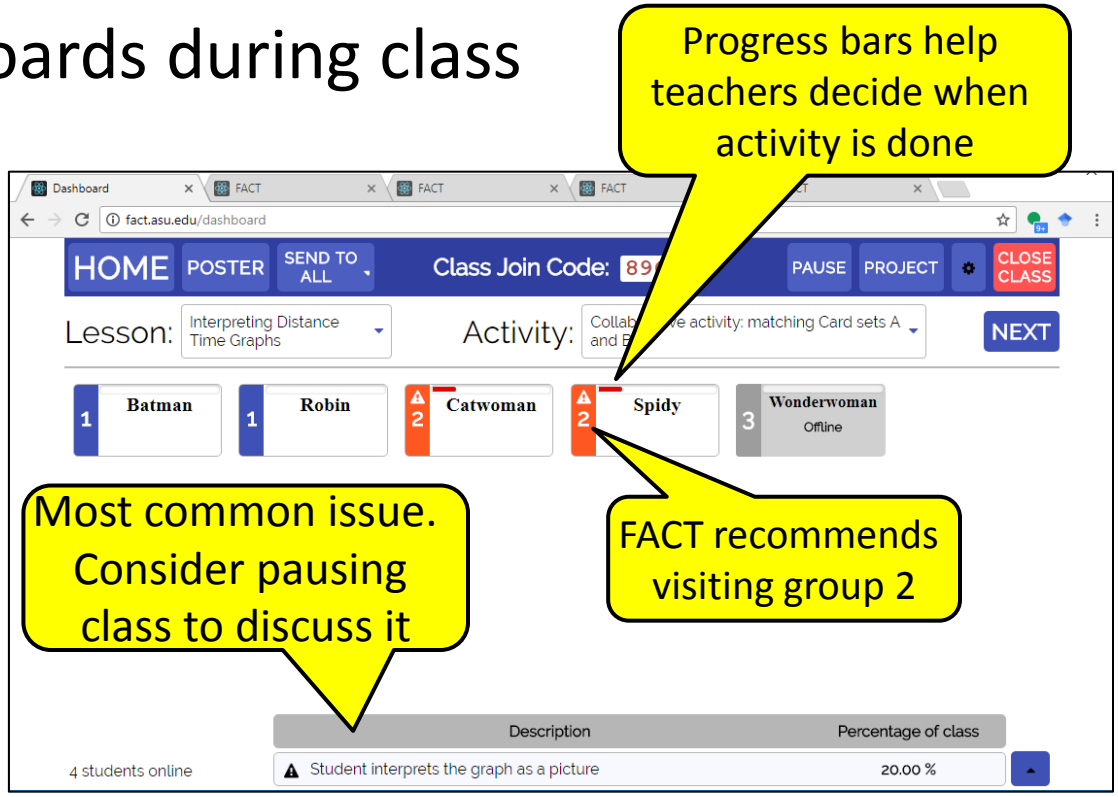
Koedinger, K. R., Pavlik, P. I., Stamper, J., Nixon, T., & Ritter, S. (2011). *Avoiding problem selection thrashing with conjunctive knowledge tracing*. Paper presented at the International Conference on Educational Data Mining, Eindhoven, NL.

ITS impact on small group work: Weak evidence

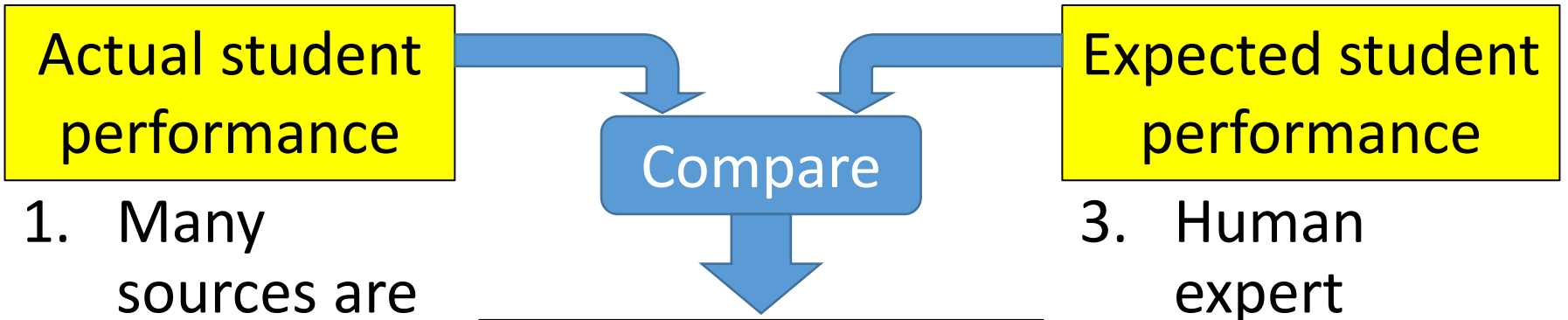
- Feedback and hints
  - Most studies focus on increasing collaboration
  - Few studies measure learning
- Selecting group members
  - Few studies measure learning

ITS impact on teachers: Weak evidence

- Freeing teachers to help neediest students
- Teachers can focus on reviewing problematic tasks
- Use of dashboards during class



Summary



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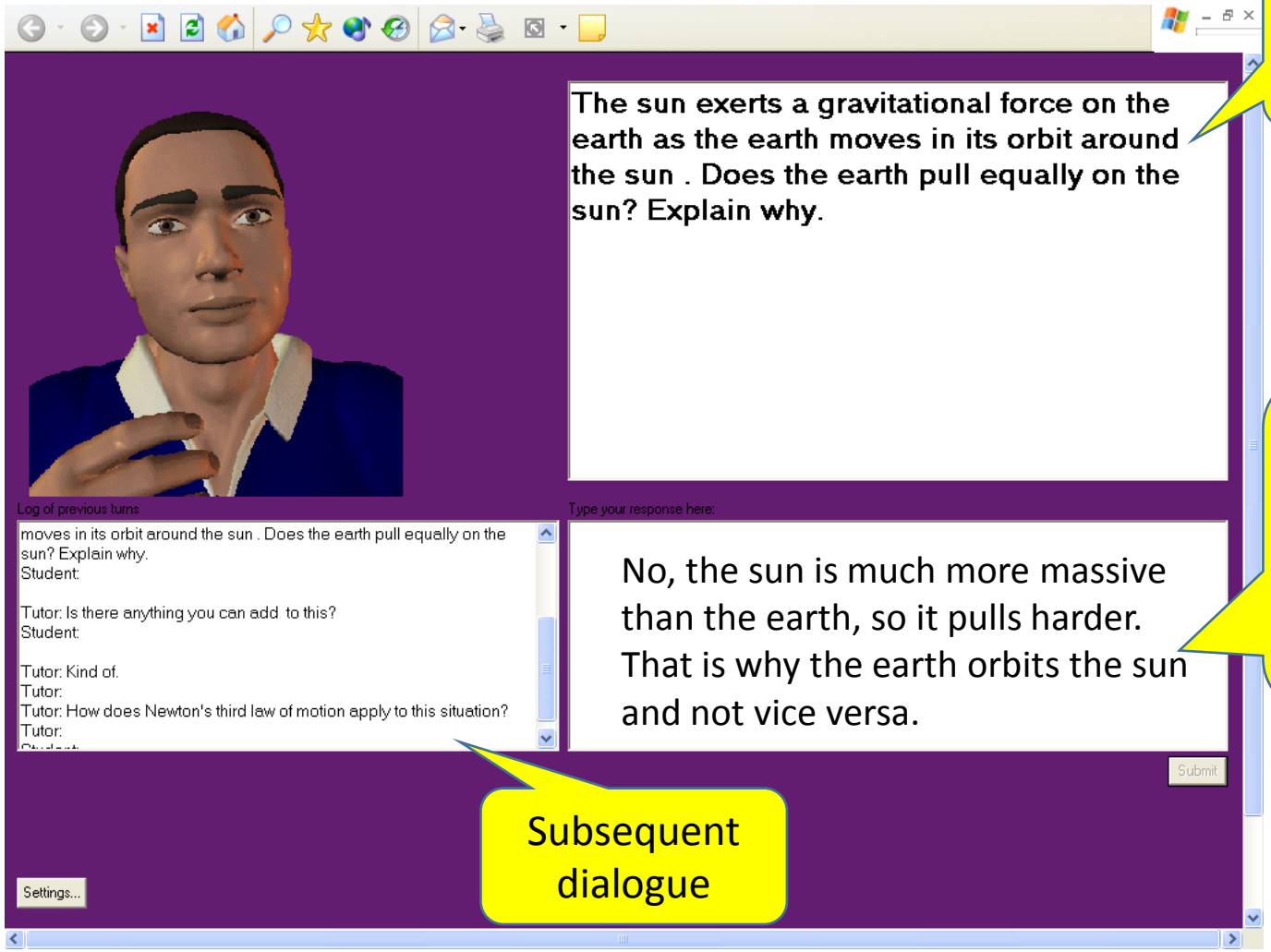
Tutor's actions to decrease difference

- Strong evidence
  - Feedback & hints
  - Mastery learning
  - Adaptive assessment
- Likely
  - Embedded assessment
- Weak evidence or effect
  - Adaptive task selection
  - Impact on small groups
  - Impact on teachers

3. Human expert authors are (still) the main source.

Thanks!
Questions?

A tutor-student dialogue that starts with an essay question



Graesser, A. C., D'Mello, S. K., Hu, X., Cai, Z., Olney, A., & Morgan, B. (2012). AutoTutor. In P. McCarthy & C. Boonthum-Denecke (Eds.), Applied natural language processing: Identification, investigation and resolution (pp. 169-187). Hershey, PA: IGI Global.