

An Introduction to Intelligent Tutoring Systems (ITS)

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

Kurt VanLehn
Arizona State University
Tempe, AZ



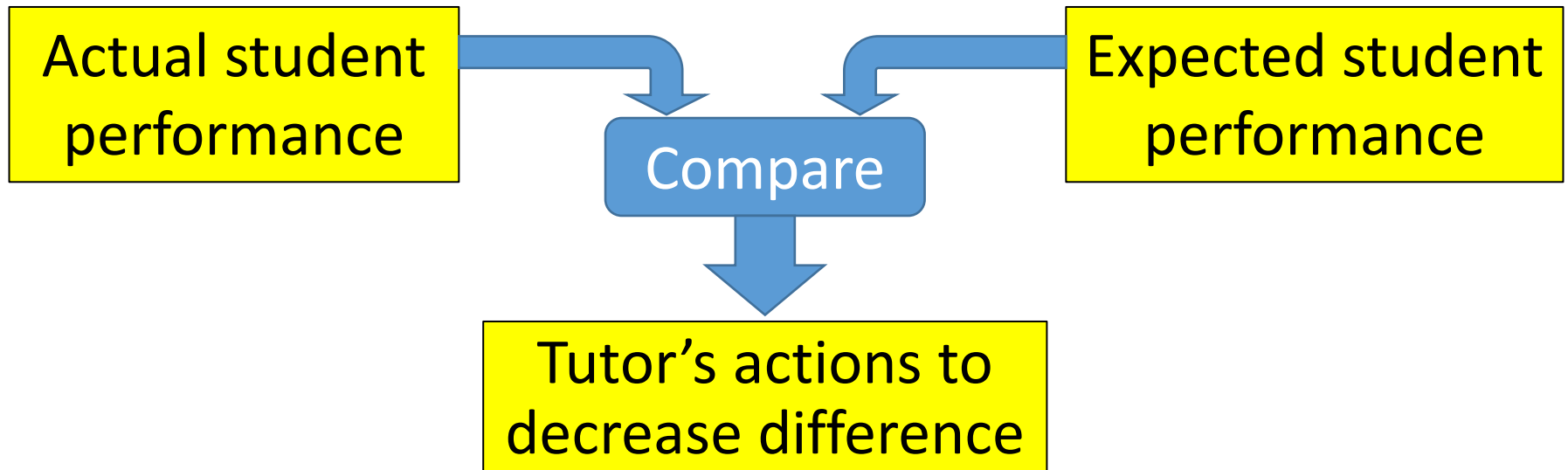
Soller et al. (2005) claim edutech innovation is either:

- **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

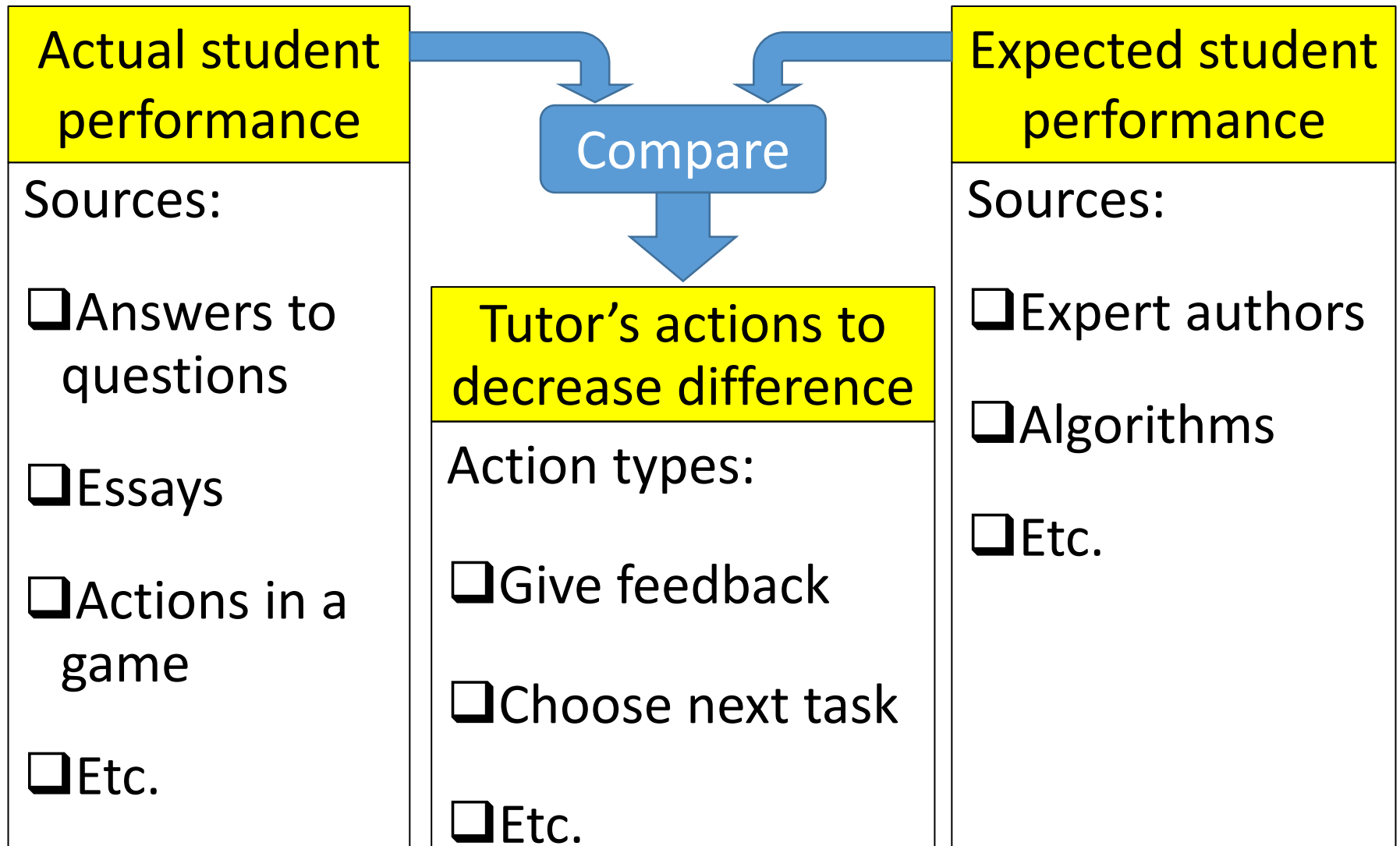
- Soller, A., Martinez, A., Jermann, P., & Muehlenbrock, M. (2005). From mirroring to guiding: A review of state of the art technology for supporting collaborative learning. *International Journal of Artificial Intelligence and Education*, 15, 261-290.
- VanLehn, K. (2016). Regulative loops, step loops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

Main components of an ITS

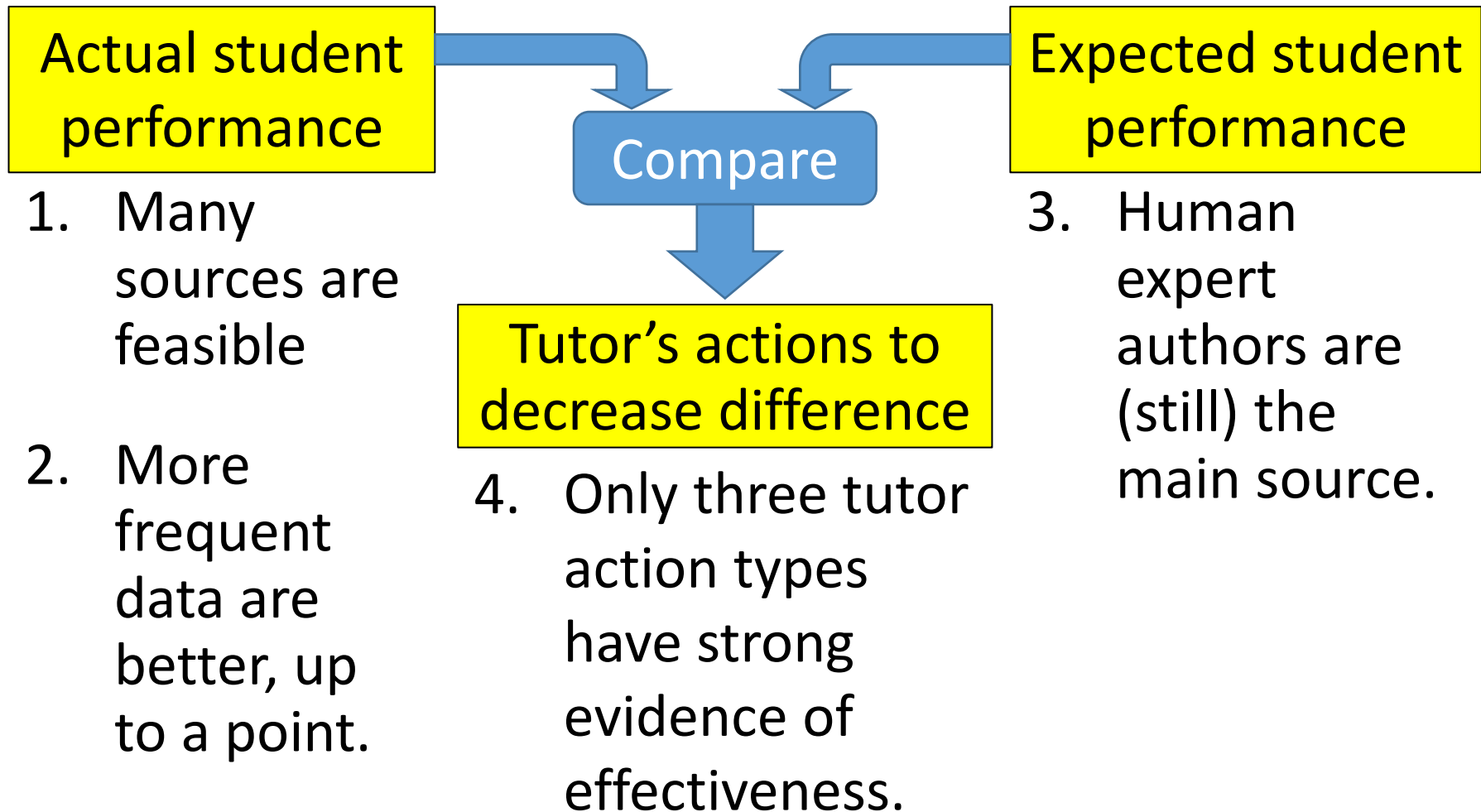
Viewed as a regulative loop



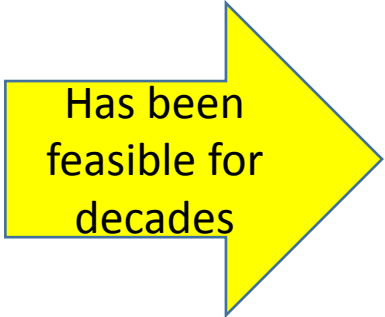
To design an ITS, choose at least one from each column



I will make 4 main points



Main sources of student performance data



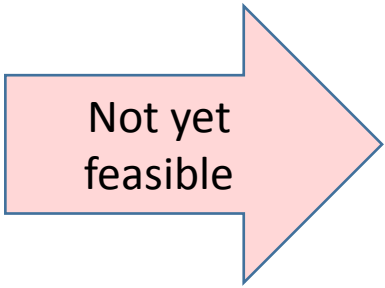
Has been
feasible for
decades

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



Now feasible

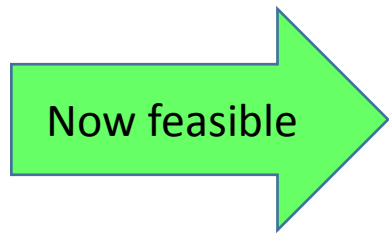
- Step-based
 - Tutor assigns task, then student makes many actions observed by the tutor (steps).



Not yet
feasible

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

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



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

An editor for solving physics problems

s5a Physics Submit

A model airplane hangs from two strings S1 and S2 which are attached to the ceiling. String S1 is inclined at 45.0 deg, and string S2 is inclined at 60.0 deg, as shown in the figure below.

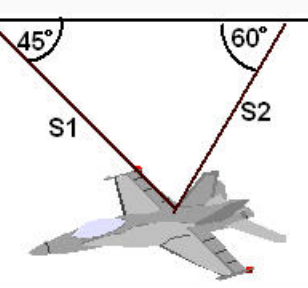
If the tension in string S1 is 50.0 N,

a) find the tension in string S2.

Answer:

b) find the mass of the airplane.

Answer:



Define time T0

g is the acceleration of gravity on earth
 $g = 9.8 \text{ m/s}^2$
 m = mass of the airplane
 Fw = weight force on the airplane
 F1 = force on airplane due to S1
 F2 = force on airplane due to S2

F1 = 50 N
 Fw = m * g

airplane

$Fw_x + F1_x + F2_x = 0$
 $Fw_y + F1_y - F2_y = 0$

Step

Step

Step

Help Score: 57%

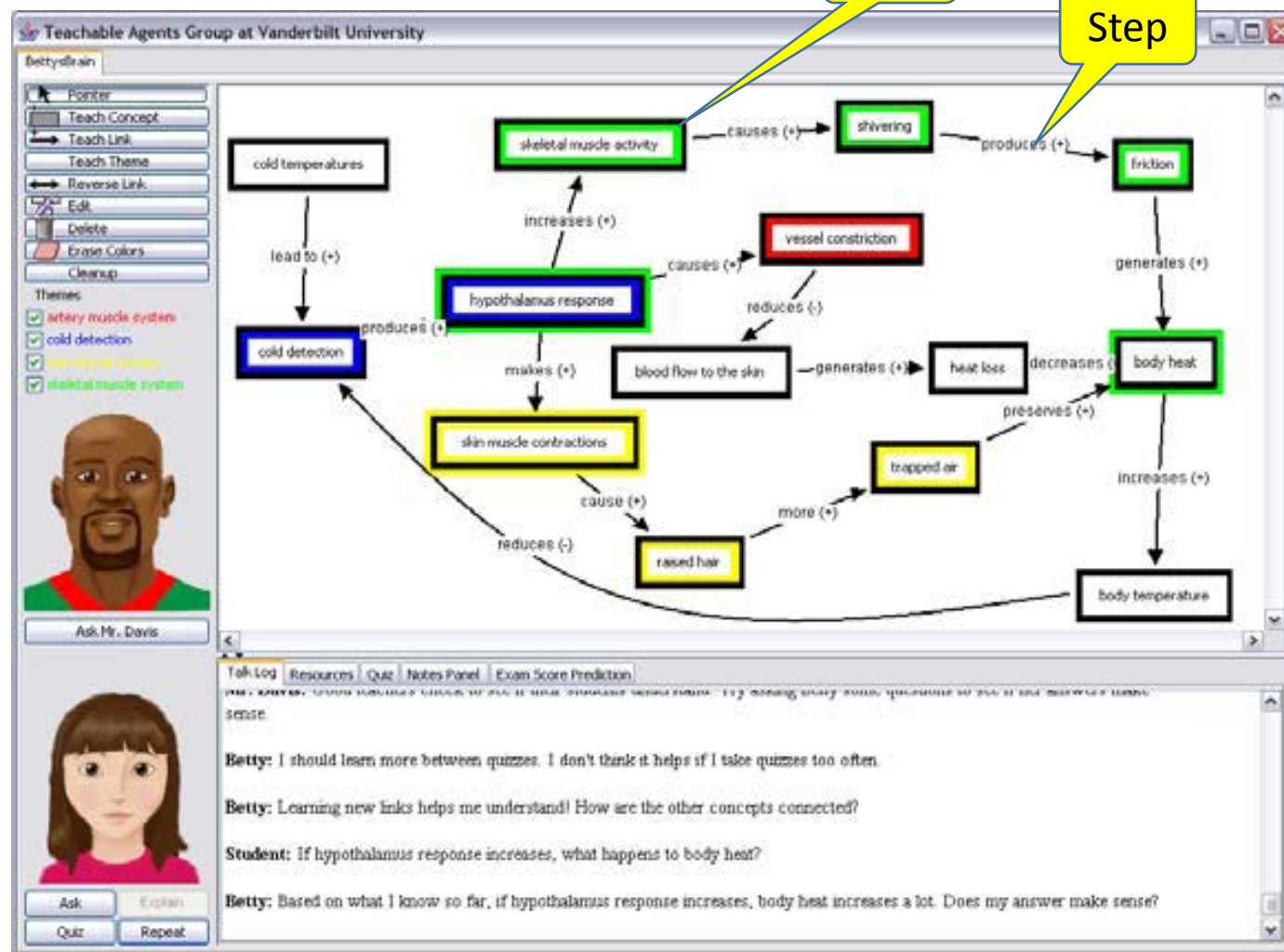
If you need help, click the help button ? below. Click the button above to hide this window.

Check your signs.

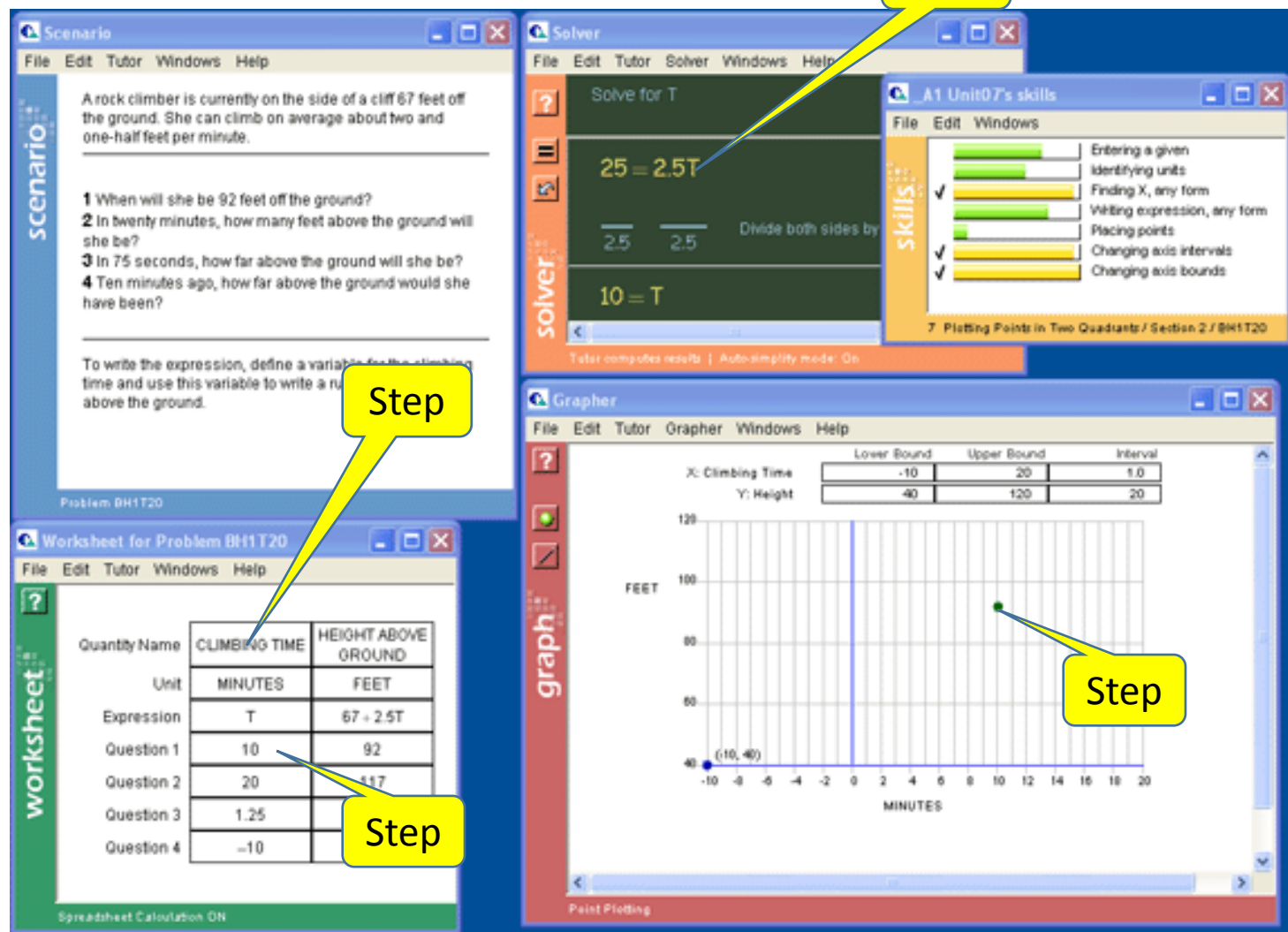
[Explain more](#)

Perhaps the sign of the F2_y term should be changed.

An editor for constructing concept maps



An editor for complex math problem solving



Tutor-student dialogue

The screenshot shows a dialogue window with a light green background. The text is as follows:

Tutor said: Okay. Please write the equation for how the definition of kinetic energy applies to this problem at T1.

You said: $value=ke1=1/2*m*v1^2$

Tutor said: Now it is easy to calculate the magnitude of v1. The magnitude of v1 is 5.0 m/s.

Tutor said: Before going on to the next step, let's think about the application of this equation.

Tutor said: Can we infer the direction of the velocity of the rock at T1 from the rock's kinetic energy at T1?

You said: no, we cannot

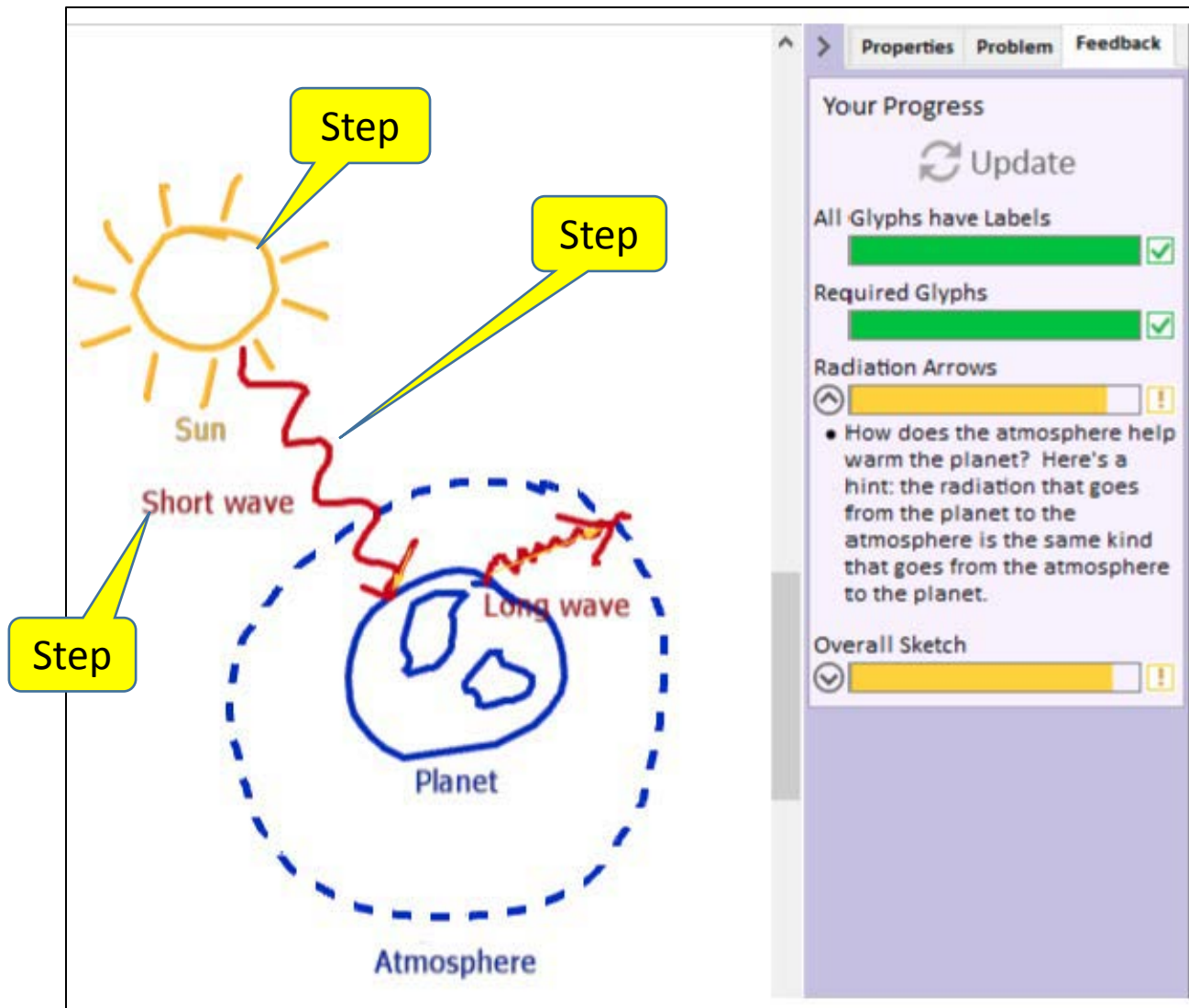
Tutor said: Excellent! Please explain why.

Only the magnitude of the velocity and not the direction of it is part of the definition of kinetic energy.

At the bottom left is an 'OK' button with a mouse cursor icon. At the bottom center is a 'Comments' label. On the right side, there are three yellow callout boxes with blue lines pointing to specific parts of the dialogue:

- Past dialogue**: Points to the first five lines of the dialogue.
- Tutor's dialog turn**: Points to the line 'Tutor said: Excellent! Please explain why.'
- Step: Student's dialog turn**: Points to the line 'Only the magnitude of the velocity and not the direction of it is part of the definition of kinetic energy.'

An editor for drawing explanations



A general-purpose collaborative editor

Rescue Helicopter

When an emergency call arrives, it takes 5 minutes to load and wait until the helicopter takes off. It is 60 miles to the accident. The helicopter flies at 1.5 miles per minute and arrives at the scene t minutes after the call.

Enter the values for t , s , d and h in the boxes:

- Time to load and wait up: minutes
- Average speed of the helicopter in flight: miles per minute
- The distance from the helicopter to the accident: miles
- Total time needed to arrive at the scene of the accident: minutes

Now enter these numbers, what could they be?

- Construct a table of possible values.
- Sketch a graph to show the relationship between these numbers.

Present this with another pair of numbers.

distance	time
60	45
60	65
120	85
180	105

Hide all the numbers. Construct a general formula for the relationship between them. Write your formula in different ways, starting tu003d..., du003d..., and so on.

Handwritten work:

- $t = \frac{d}{s} + W$
- $-W \frac{d}{s} + W$
- $t - W = \frac{d}{s}$
- $s(t - W) = d$
- $t - W = \frac{d}{s}$
- $d = s(t - W)$
- $t = \frac{d}{s} + W$
- $1.5 \times 9 = 13.5$
- $13.5 \times 5 = 67.5$
- $67.5 + 5 = 72.5$
- $1050 \div 15 = 70$
- $105 \div 15 = 7$
- $15 \times 80 = 1200$
- $15 \times 125 = 1875$
- $15 \times 140 = 2100$
- $15 \times 105 = 1575$
- $15 \times 60 = 900$
- $15 \times 45 = 675$
- $15 \times 30 = 450$
- $15 \times 15 = 225$
- $15 \times 0 = 0$
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- $15 \times -5775 = -86625$
- $15 \times -5790 = -86850$
- $15 \times -5805 = -87075$
- $15 \times -5820 = -87300$
- $15 \times -5835 = -87525$
- $15 \times -5850 = -87750$
- $15 \times -5865 = -87975$
- $15 \times -5880 = -88200$
- $15 \times -5895 = -88425$
- $15 \times -5910 = -88650$
- $15 \times -5925 = -88875$
- $15 \times -5940 = -89100$
- $15 \times -5955 = -89325$
- $15 \times -5970 = -89550$
- $15 \times -5985 = -89775$
- $15 \times -6000 = -90000$
- $15 \times -6015 = -90225$
- $15 \times -6030 = -90450$
- $15 \times -6045 = -90675$
- $15 \times -6060 = -90900$
- $15 \times -6075 = -91125$
- $15 \times -6090 = -91350$
- $15 \times -6105 = -91575$
- $15 \times -6120 = -91800$
- $15 \times -6135 = -92025$
- $15 \times -6150 = -92250$
- $15 \times -6165 = -92475$
- $15 \times -6180 = -92700$
- $15 \times -6195 = -92925$
- $15 \times -6210 = -93150$
- $15 \times -6225 = -93375$
- $15 \times -6240 = -93600$
- $15 \times -6255 = -93825$
- $15 \times -6270 = -94050$
- $15 \times -6285 = -94275$
- $15 \times -6300 = -94500$
- $15 \times -6315 = -94725$
- $15 \times -6330 = -94950$
- $15 \times -6345 = -95175$
- $15 \times -6360 = -95400$
- $15 \times -6375 = -95625$
- $15 \times -6390 = -95850$
- $15 \times -6405 = -96075$
- $15 \times -6420 = -96300$
- $15 \times -6435 = -96525$
- $15 \times -6450 = -96750$
- $15 \times -6465 = -96975$
- $15 \times -6480 = -97200$
- $15 \times -6495 = -97425$
- $15 \times -6510 = -97650$
- $15 \times -6525 = -97875$
- $15 \times -6540 = -98100$
- $15 \times -6555 = -98325$
- $15 \times -6570 = -98550$
- $15 \times -6585 = -98775$

A multiplayer game


The screenshot displays a virtual environment where a player, seen from behind, sits at a desk in a room with a bookshelf and a framed picture. A female character in a white lab coat and skirt stands nearby. The interface includes several windows:

- Diagnosing an epidemic**: A yellow callout box pointing to the 3D environment.
- 3-D ENVIRONMENT WINDOW**: A red label pointing to the 3D scene.
- TEAM CHAT WINDOW**: A red label pointing to a chat area with text from 'Dr. Jones' and 'Brian Nelson (Nurse Patterson)'. A yellow callout box labeled 'Step' points to this window.
- Administrative Chart Note**: A blue header for a 'Hospital Admissions Chart' with tabs for 'Unit 1', 'Unit 2', and 'Unit 3'. It contains a question: 'Where are the sick people coming from? Are there any differences in numbers between different areas?'.
- INDIVIDUALIZED GUIDANCE SYSTEM**: A red label pointing to the chart header.
- River = City**: A text label above the chart.
- Hospital Admissions Chart**: A table with columns: Name, Age, Address, Reason for Visit, and Date.

Name	Age	Address	Reason for Visit	Date
Agatha Pearson	54	Tenement #2	diarrhea and stomach pain	10/10/1879
Abby Woods	6	Tenement #2	night sweats, severe cough, chest pain—2nd admission	10/5/1879
Cliff Johnson	51	Tenement #1	Mild stomach pain and	10/12/1879
- CONTENT WINDOW**: A red label pointing to the 'Reason for Visit' column in the chart.
- TOOLBAR**: A red label pointing to a set of navigation icons.
- HEALTH METER**: A red label pointing to a blue bar at the bottom right.

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?



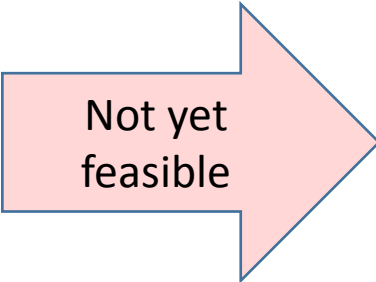
Has been
feasible for
decades

- 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

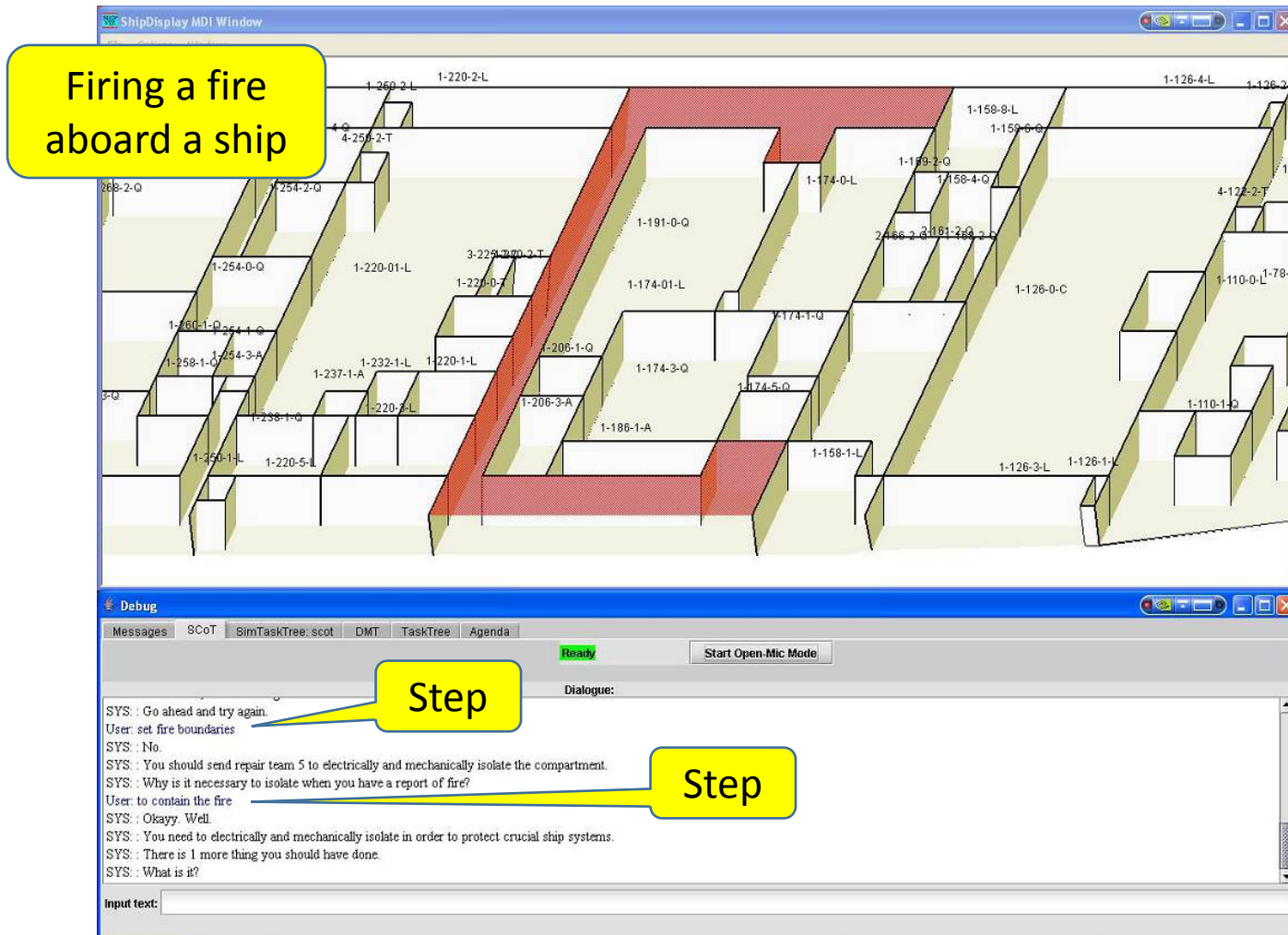


1. RTO: steel one niner this is gator niner one adjust fire polar over
2. FSO: gator nine one this is steel one nine adjust fire polar out
3. RTO: direction five niner four zero distance four eight zero over
4. FSO: direction five nine four zero distance four eight zero over

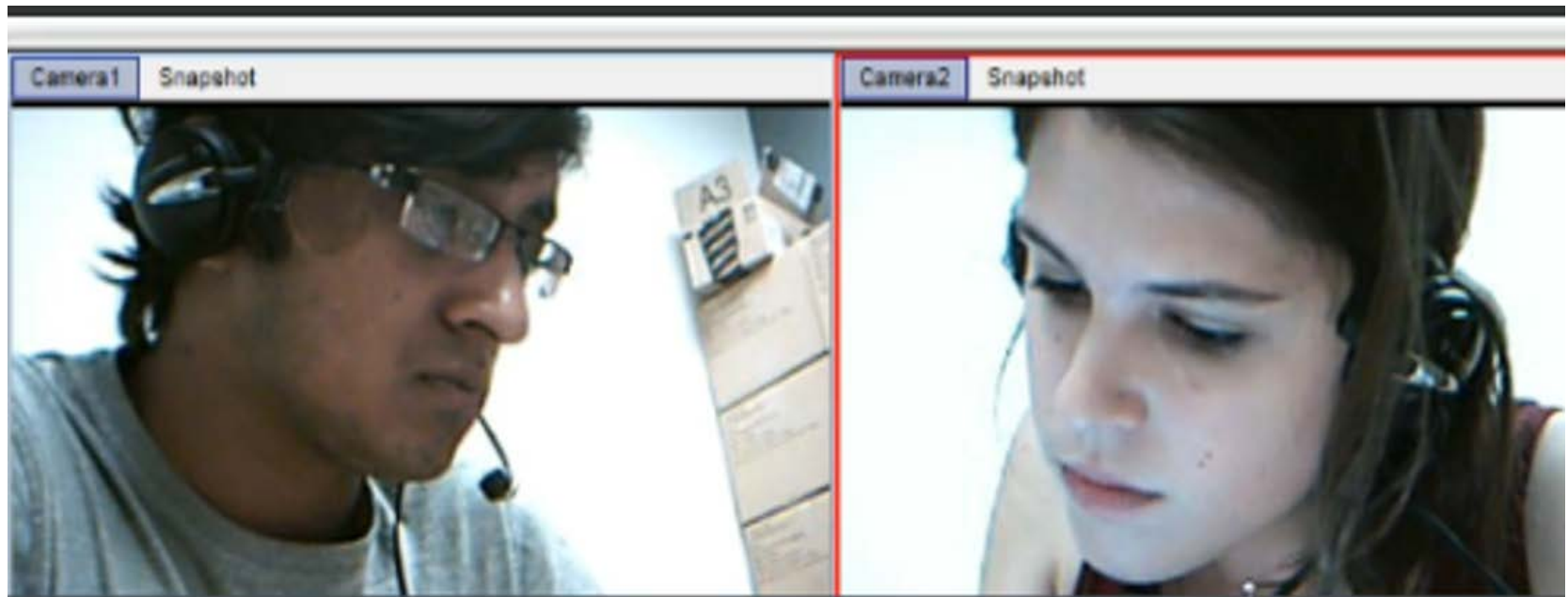
Step

Step

Tutors can understand short answers to their questions

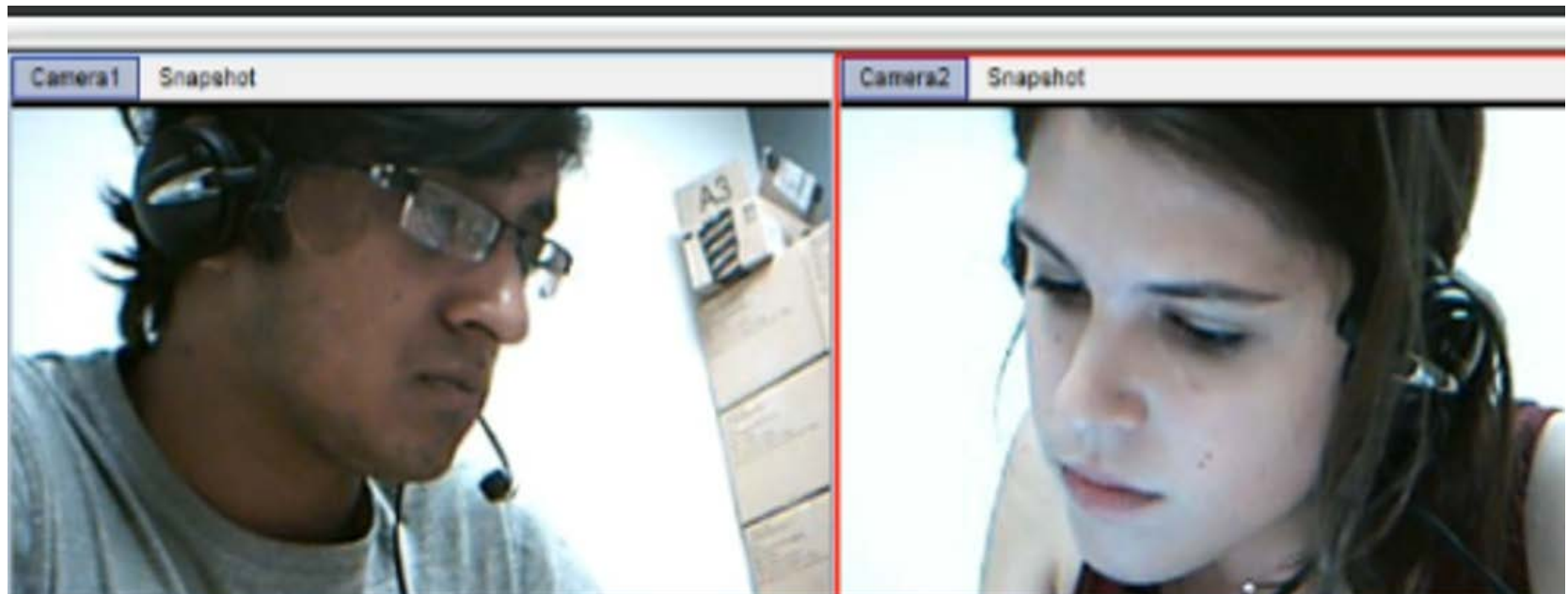


Tutors can understand affect & collaboration in spoken conversations in lab settings

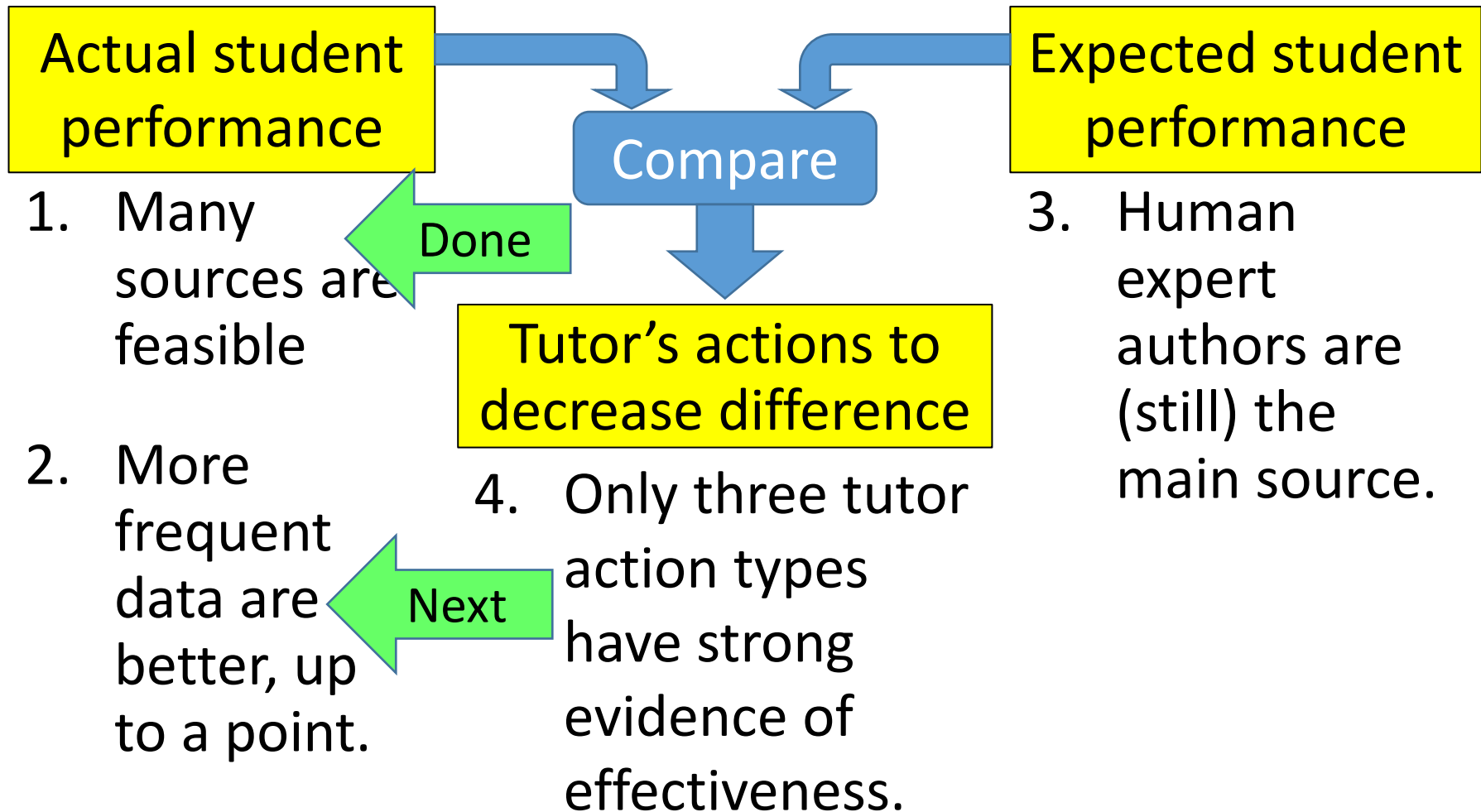


- Viswanathan, S. A., & VanLehn, K. (in press). Using the tablet gestures and speech of pairs of students to classify their collaboration. *IEEE Transactions on Learning Technologies*.
- Forbes-Riley, K., & Litman, D. (2014). Evaluating a spoken dialogue system that detects and adapts to user affective 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



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

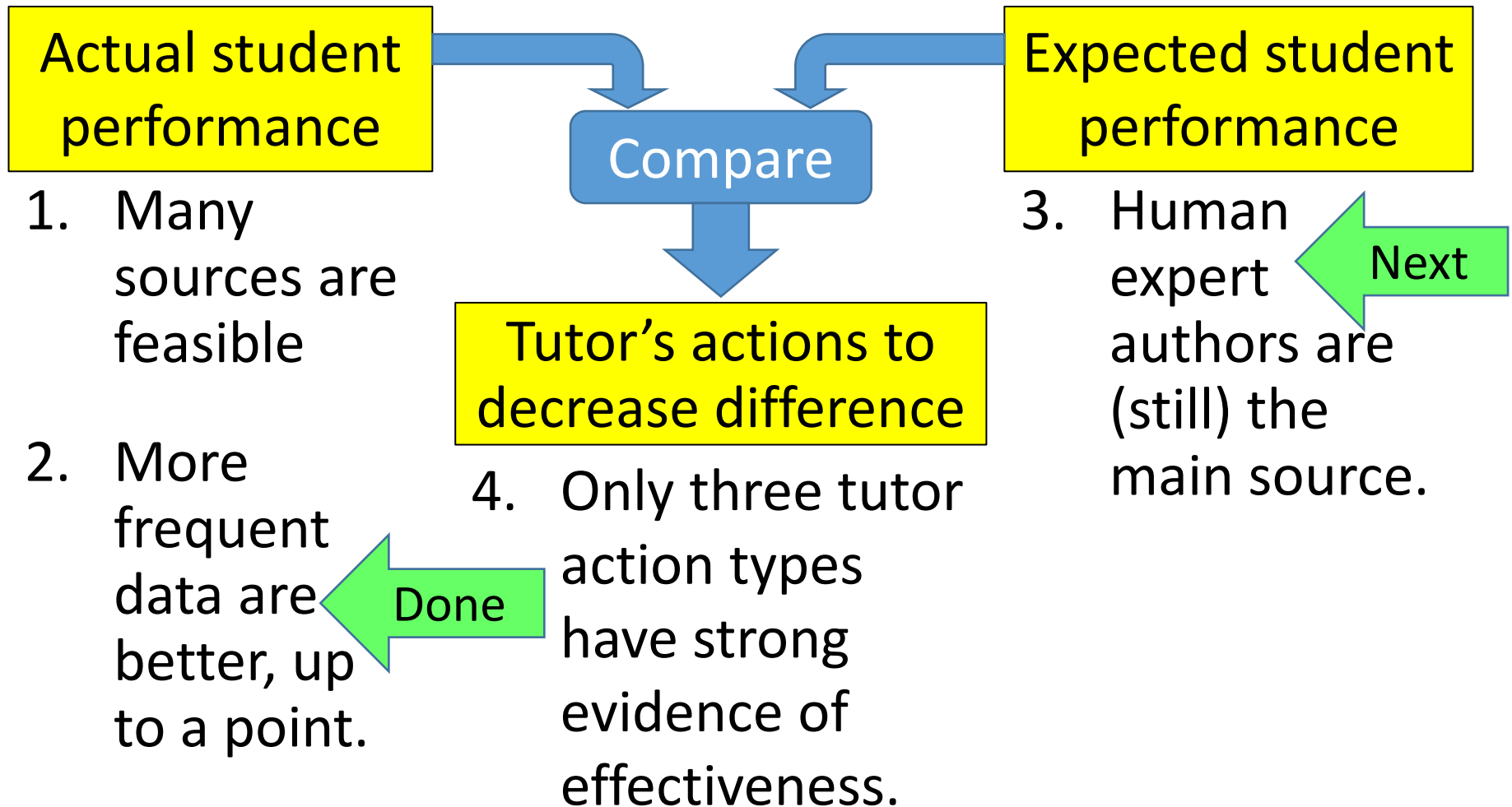
- Answer-based > no tutoring by 0.30
- Step-based tutoring > answer-based by 0.45
- Human tutoring = step-based tutoring

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

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

Main points: Transition slide

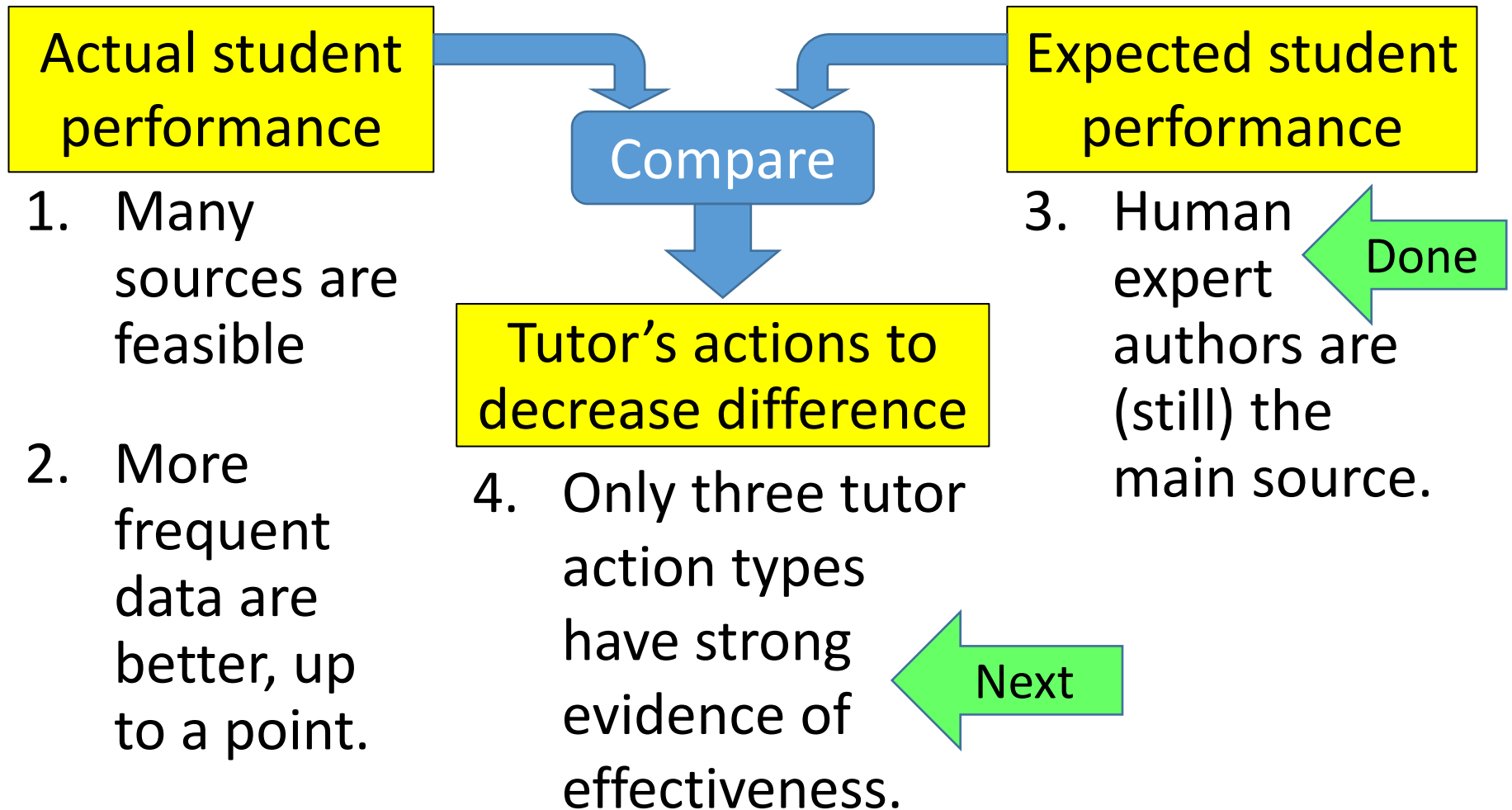


Authoring:

- 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



Common activities in classes.

ITS are
feasible

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



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

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

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

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

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- Let the learner, not the system, choose tasks
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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?

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

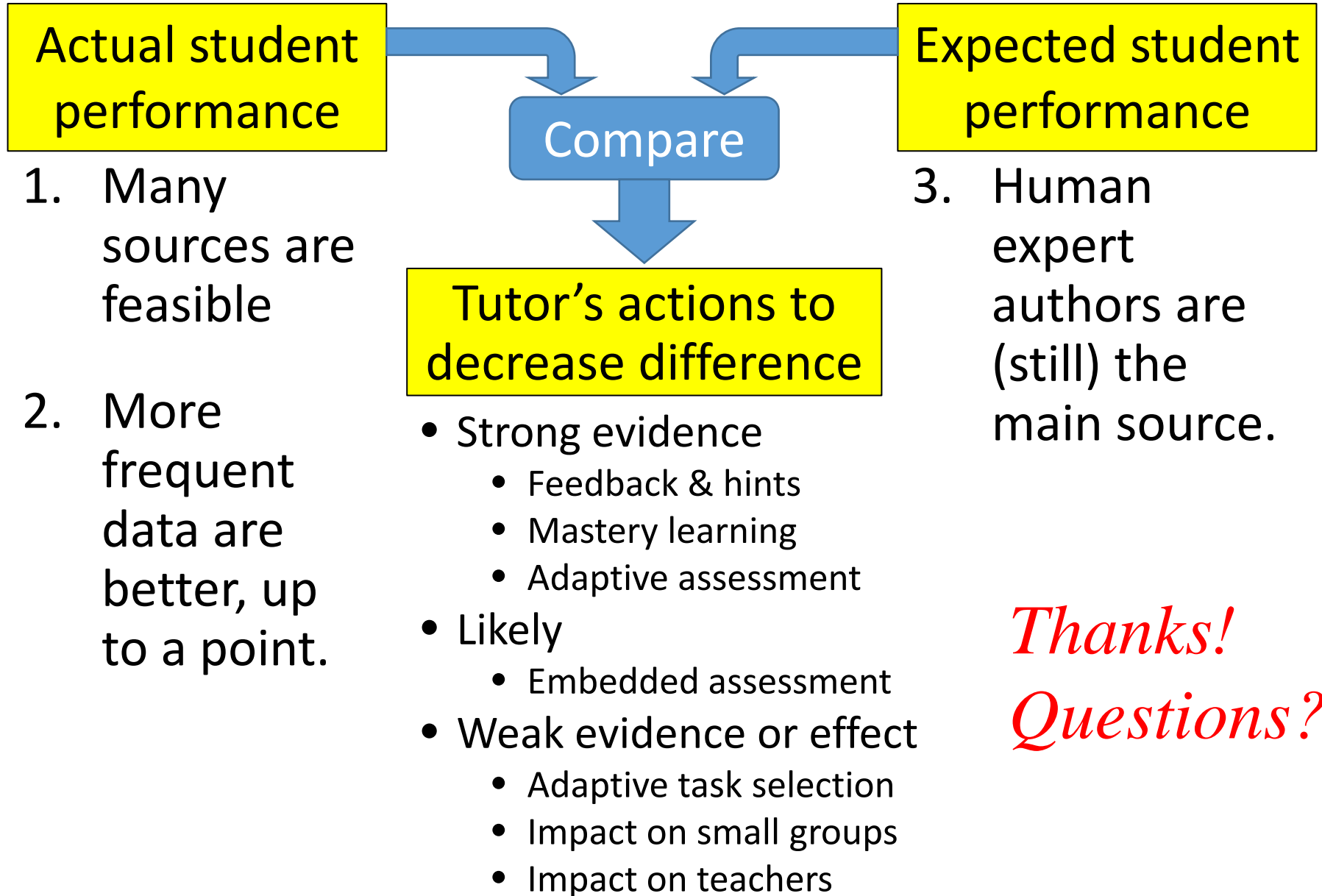
ITS impact on **teachers**:

Weak evidence

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



Summary



Thanks!
Questions?

A tutor-student dialogue that starts with an essay question

The screenshot displays the AutoTutor interface, which includes a 3D avatar of a male tutor on the left. The main area contains a text box with the question: "The sun exerts a gravitational force on the earth as the earth moves in its orbit around the sun . Does the earth pull equally on the sun? Explain why." Below this is a text box for the student's response, which contains the answer: "No, the sun is much more massive than the earth, so it pulls harder. That is why the earth orbits the sun and not vice versa." A "Submit" button is located at the bottom right of the response box. On the left side, there is a "Log of previous turns" section showing a history of the dialogue. Three yellow callout boxes provide additional context: one points to the question text, another points to the student's answer, and a third points to the dialogue log.

Tutor's initial question

Student's initial answer is short essay, analyzed into propositions (steps).

Subsequent dialogue

The sun exerts a gravitational force on the earth as the earth moves in its orbit around the sun . Does the earth pull equally on the sun? Explain why.

Type your response here:

No, the sun is much more massive than the earth, so it pulls harder. That is why the earth orbits the sun and not vice versa.

Submit

Log of previous turns

moves in its orbit around the sun . Does the earth pull equally on the sun? Explain why.
Student:

Tutor: Is there anything you can add to this?
Student:

Tutor: Kind of.
Tutor:
Tutor: How does Newton's third law of motion apply to this situation?
Tutor:
Student:

Settings...