Rimac: A Natural-language Tutoring System that Engages Students in Deep Reasoning Dialogues about Physics

Sandra Katz, Michael Ford, Pamela Jordan, Diane Litman (co-PI's)
Patricia Albacete, Michael Lipschultz, Scott Silliman, Christine Wilson
University of Pittsburgh

Project Goals

Scientific goal:

Test a hypothesis about what makes human one-on-one tutoring very effective:

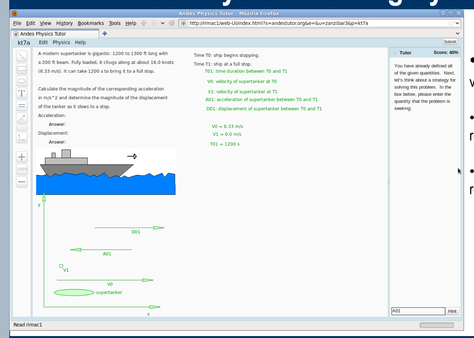
- Abstraction and specialization support learning
  - Initial support from our prior research

Development goal:

Improve an already effective physics tutoring system, Andes

- Increase its ability to help students understand physics concepts, not just to be good problem solvers
- Approach: Engage students in mostly qualitative, "reflective discussions" after they solve quantitative problems

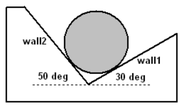
Andes Physics Tutoring System



- Web-based version of Andes
- Gives immediate red/green feedback
- Help available on request

Example of an Automated "Reflective Dialogue"

Problem: A spherical ball with a mass of 2.00 kg. rests in the notch shown below. If there is no friction between the ball and the walls, what is the magnitude of the force exerted on the ball by wall 1?



Reflection Question: Let's review a few things about the Andes problem you just completed, to better help you solve related problems in the future. Which major principles did you need to solve the problem [just the name, please]

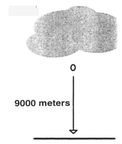
Student: newton's second law
Tutor-2: What was the magnitude of the ball's net acceleration?
Student: 0
Tutor: What was the magnitude of the net force on the ball?
Student: 0
Tutor: What is the magnitude of the x-component of the weight force?
Student: 0
Tutor: Good. The weight force on the ball had no x-component because the direction of gravity is straight down. What does this tell you about the x-components of the forces on the ball from each wall?...

What Human Physics Tutors Do

- Take what the student said and talk at a higher, more ABSTRACT level (*abstraction)*
  - E.g., use more formal, symbolic terms; highlight general concepts or principles
- Talk at a more SPECIFIC level (*specialization)*
  - E.g., distinguish between sub-concepts, such as the different types of acceleration; probe students to specify units, direction, etc.
- We found that abstraction and specialization during tutoring predict pre-test to post-test learning gains.

Example of Abstraction in Human-Human Reflective Dialogue

Problem: Calculate the speed at which a hailstone, falling from 9000 meters out of a cumulonimbus cloud, would strike the ground, presuming that air friction is negligible.

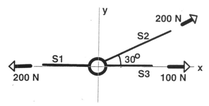


Reflection Question: How do we know that we have an acceleration in this problem?

Student: b/c the final velocity is larger than the starting velocity, 0.
Tutor: Right, **a change of velocity implies acceleration**.

Example of Specialization in Human-Human Reflective Dialogue

Problem: In the figure below, each of the three strings exerts a tension force on the ring as marked. Use the labels S1, S2 and S3 to refer to the three strings. Find the components of the net force acting on the ring.



Reflection Question: What if I now told you that this ring has an acceleration. If you knew the mass of the ring (3 kg) how would you solve for the acceleration?

Student: 73.2=3*a; 100-Fw=3*a. Is this right; how would the accel [sic] be the same for both?
Tutor: **you have to keep the a_x and the a_y distinguished. They are two completely independent numbers that (together with a_z) specify your acceleleration vector. So 73.2 N = 3 kg * a_x; 100 N = 3 kg * a_y.** You don't try to boil them down to one number. It's like if I told you "To get to my house you go 3 blocks north and 5 blocks east" and you said "Ah so you just go 8 blocks" – the two numbers together are the vector, they don't "boil down" to one number. OK?
Student: but can't it only have one acceleration?
Tutor: **it does only have one acceleration but that acceleration is a vector and it takes 3 numbers to write it down**. You need to review vectors in some detail; **a_x, a_y, and a_z together specify the acceleration vector.…**

Our Challenge: To Identify When Human Tutors Abstract and Specialize

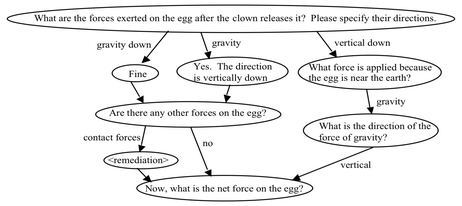
- Goal is to specify *decision rules* for abstraction and specialization that can be implemented in tutoring system.
- One approach: detailed analysis of a corpus of human-human reflective dialogues in Andes, in order to describe the *contexts* in which cases of abstraction and specialization occur.
  - Then we define general decision rules that apply across several cases.
- Another approach: machine learning analysis of features that predict abstraction and specialization (Lipschultz et al., *FLAIRS 2011* paper)
  - 3 types of features: student (e.g., sex, pretest score), solution (e.g., number of errors), and contextual (e.g., length of previous turn)
  - Contextual features best predictors of abstraction and specialization

Example of a Decision Rule for Abstraction
When a student correctly instantiates a physics law, the tutor follows up with a general statement of that law:

Student: the bullet's force is to the right, so the vest's force is to the left
Tutor: equal and opposite pair of forces

The Reflective Dialogue System

- Uses **TuTalk**, a natural-language dialogue platform for authoring and field testing tutorial dialogues
  - Several NL tutoring systems that have been shown to promote learning were developed using TuTalk, e.g., Andes-Atlas, Why2-Atlas, ITSpoke, and Cordillera
- One style of learning dialogues that TuTalk supports is Knowledge Construction Dialogues (KCDs)
  - Represented as a finite state machine (FSM)
    - Each oval in figures below represent a tutor turn (state)
    - Each arrow represents a *class* of possible student replies (arc)



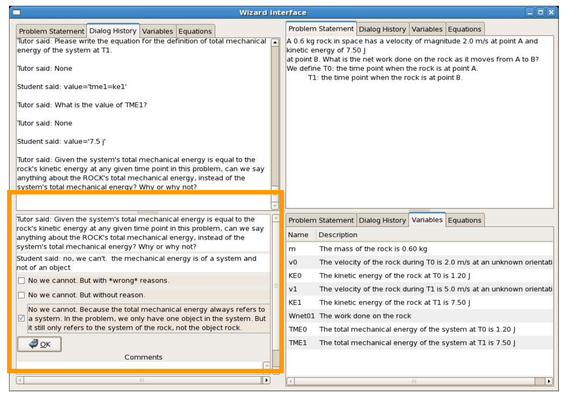
The dialogue paths of three students as they traverse the arcs in a KCD

Project Schedule

- Years 1 and 2 (6/1/10 – 5/31/12)
  - 4 cycles of reflective dialogue development and field testing
    - Test system on college students first , then high school students
  - Physics teachers help with system development
    - interpret student input
    - provide feedback on system decisions to specialize or abstract, which we will use to refine our decision rules
- Year 3 (6/1/12 – 5/31/13)
  - Pilot test: high school classes use Andes with reflective dialogues, during selected topics
  - Tutoring system interprets and responds to student input on its own

Example of Teacher Interface for Interpreting Student Dialogue Input

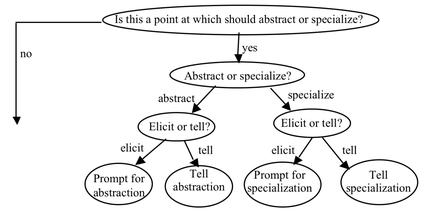
- Teacher sees all content of student's interface.
- But only the teacher has the highlighted pane in figure below
  - Checks the closest match of the possible responses (arcs) to student's response
  - Provides additional feedback to developers in comment box



From Cordillera Tutoring System

Decision Rules Will Be Added to System and Refined, Based on Teachers' Feedback

- System must decide when it is appropriate to abstract or specialize and how to do so (e.g., ask vs. tell), as in decision tree figure below
- Initial decision-making model will
  - Use decision rules to identify when (in what contexts) abstraction and specialization are appropriate
  - Compare where in an ontology of physics concepts student input is, relative to what system expected and
    - Specialize if student concept is higher than expected
    - Abstract if student concept is lower than expected



Abstract/Specialize Decision Tree

Acknowledgements

Funding: Institute of Education Sciences Grant # R305A100163

Andes Technical Support: Kurt VanLehn & Brett van de Sande, Arizona State University