Problem Solving Coaches in Physics Tutoring
Part 1: Background and Model

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Background Considerations

- Problem solving is considered a highly desirable skill by educators (Carney 2006) and employers (National Academies Press 2007, Martinez 1998, Jonassen 2007) alike

- Specific interest in introductory physics course to teach problem solving (Foster, Heller and Heller 1998)
  - Survey of faculty teaching calc-based introductory physics - engineering, science, computer science, etc.

"Raising the Bar: Employers' Views on College Learning in the Wake of the Economic Downturn" (January, 2010) –

- **Hart Research Associates** – survey of 302 employers, 2009
- percentage of employers who wanted colleges to "place more emphasis" on the following:
- *Intellectual and practical skills*

The ability to communicate effectively, orally and in writing (89%)

Critical thinking and analytical reasoning skills (81%)

The ability to analyze and solve complex problems (75%)

Teamwork skills and the ability to collaborate with others in diverse group settings (71%)

The ability to innovate and be creative (70%)

The ability to locate, organize, and evaluate information from multiple sources (68%)

The ability to work with numbers and understand statistics (63%)

Table 3

Goals for the Introductory Physics Course

Goal	Weighted Average	Unweighted Average
Know the basic principles behind all physics (e.g. forces, conservation of energy, ...)	4.5 ± 0.1	4.7 ± 0.1
Solve problems using general qualitative logical reasoning within the context of physics	4.5 ± 0.3	4.7 ± 0.2
Solve problems using general quantitative problem solving skills within the context of physics	4.3 ± 0.3	4.6 ± 0.2
Apply the physics topics covered to new situations not explicitly taught by the course.	4.2 ± 0.3	4.5 ± 0.2
Use with confidence the physics topics covered.	4.2 ± 0.3	4.1 ± 0.2
Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, plasmas, ...)	3.9 ± 0.4	4.3 ± 0.3

Foster, Heller and Heller 1998

Experts vs. Novices

- Experts look for the basic principles underlying the problem, while novices tend to focus on the surface features of the problem (Chi et al, 1981)

- Experts tend to do a qualitative description about the problem features and expectations before writing down quantitative relationships, while novices tend to plug in pieces of information and write miscellaneous equations (Chi et al., 1981; Larkin, 1979; Larkin, 1982; Larkin et al., 1980; Larkin & Reif, 1979, Reif & Heller, 1982).

- It is possible to improve students' problem-solving skills significantly through targeted efforts

Cognitive Apprenticeship - Basis

- A model of instruction that is accessible within the framework of the typical American classroom.
- A model that goes back to apprenticeship but incorporates elements of schooling
  - Based on traditional apprenticeship
  - Difference between visible training (e.g. how to cut someone's hair) and invisible training (e.g. problem-solving)

Cognitive Apprenticeship elements

- Modeling---Minnesota framework/framework in computer coaches
- Coaching---Discussion & lab section/Coaching provided by computer
- Fading---withdraw of help from the instructor/withdraw help from computer

- Scaffolding---support the instructor gives the students/support from the computer (could be hint, could be feedback)

Collins, Brown, and Newman, 1989

Farnham-Diggory, 1990

Motivation & Background

- "Competent Problem Solver" and the Minnesota problem solving framework (Heller and Heller, 1995)

Minnesota problem-solving framework

1. Focus the problem
   - Draw a picture illustrating the situation
   - Determine the question to be answered
   - Choose which physics principle(s) to use
2. Describe the physics
   - Draw physics diagrams
   - Determine target quantity(ies)
   - Write down quantitative relationships
3. Plan the solution
   - Select equation containing the target quantity
   - Identify other unknowns in equation
   - Solve a sub-problem to find each unknown
   - Check units
4. Execute the plan
   - Calculate value of target quantity(ies)
5. Evaluate the answer
   - Check if answer is properly stated
   - Check if answer is unreasonable
   - Check if answer is complete

FIGURE 1. The Minnesota problem-solving framework.

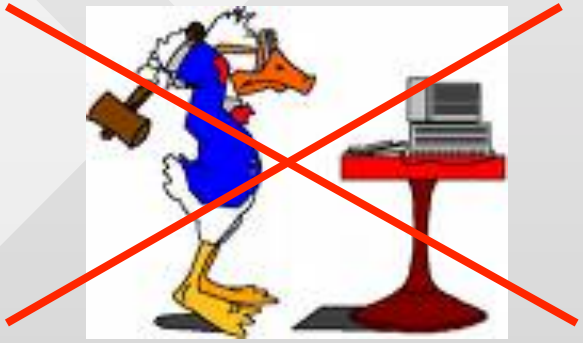
The **modeling** framework is based on the heuristics and strategies that expert problem solvers use to attack problems (e.g. Polya 1945).

It externalizes the steps experts take to plan, execute, and evaluate a solution.

Motivation & Background

- After such a process is modeled, students practice using the framework to solve problems, getting 'coaching' from an instructor or peers.
- However, individual coaching is limited and not necessarily always available for students to practice solving problems while receiving feedback.

So that's why we design computer coaches.



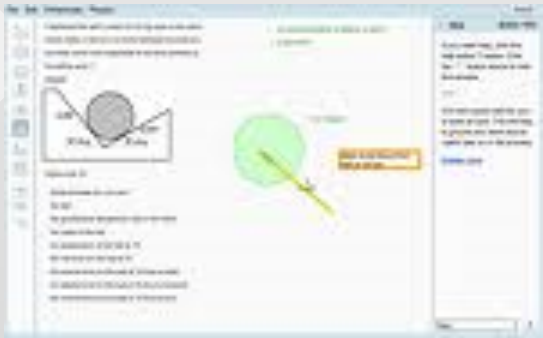
Considerations in Designing Coaching

- Reciprocal teaching (Palincsar and Brown 1984)
  - Initially reading comprehension exercise but works for many subjects
  - "Best way to learn is to teach"
- Context-rich problems (Heller and Hollabaugh 1992)
  - avoid "surface feature" focus, force students to make decisions
  - In cognitive apprenticeship, the challenge is to situate the abstract tasks of the school curriculum in contexts that <u>make sense</u> to students
  - Students need to be able to transfer their knowledge learned from one problem to another

Computer Tutor Systems (aka Intelligent Tutoring Systems) - Examples

- Earlier work with physics problems
  - PLATO (Sherwood 1971, Smith and Sherwood 1976) – command prompt system for specific topics in physics
  - ALBERT (Oberem 1987, 1994) – specific topics in physics (1-d kinematics), expanded to free-body diagrams and other areas outside of physics
  - HAT (Dufresne et al. 1992) – guided students through a conceptual expert-like problem solving strategy that seemed to aid categorization of problems (also see Chi et al. 1981)

- More recent work
  - Andes (VanLehn et al. 2005) – intensive feedback and guide through problems while allowing the student to work independently as much as possible
  - Web-based tutoring, Socratic method:
    - Tycho (Stelzer and Gladding 2001) – step-by-step heuristics
    - Cybertutor (Pritchard and Morote 2002) – emphasis on fair grading mechanism



PALs (Personal Assistants for Learning)

- Reif and Scott (1999), Scott (2001)
- Employed a cognitive analysis of the thought processes required and were based on the cognitive apprenticeship approach
- Computers and students alternately coach each other (Palincsar and Brown 1984)
- PALs specifically designed to teach the application of Newton's laws

Our tutor

(Hsu and Heller 2009)

- Based on the Competent Problem Solving framework used at the University of Minnesota (Heller and Heller 1995)
- Draws upon cognitive apprenticeship (Collins et al. 1989)
- Uses context-rich problems (Heller and Hollabaugh 1992)
- System of coaching: 3 types of tutors based on ideas used by Reif and Scott (1999, 2001)

Coming up in Part 2

- Description of the 3 types of tutors
  - Computer coaches student
  - Student coaches computer
  - Independent solution

- Proposal of a study
  - Will students benefit from the availability of tutors based on specific approaches (e.g. dynamics)?
  - Using a designed performance rubric (Docktor 2009) to determine effect on student performance

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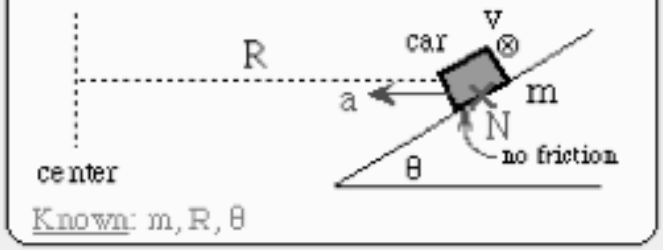
System diagram for the car

Situation (Side view)

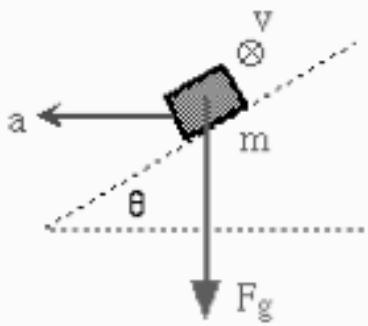


Known: m, R, θ

Diagram of system (•Draw)
Mass (•Specify mass)
Motion (•Velocity) (•Acceleration)
All forces on system
Long-range forces
• Interacting objects?
• Forces on system
Contact forces
• Touching objects? Label contacts
• Forces on system
Components (•Directions?) (•Vectors?) (•Draw)

<2>

Car (system diagram)



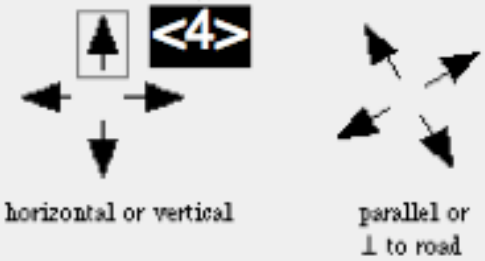
$a = \frac{v^2}{R}$

$F_g = mg$

<1>

Specify the force on the car by the road. <3>

> **Direction** (Click on an arrowhead or other choice.)



<4>

• **Into screen** ⊗
• **Out of screen** ⊙
• **None** (Vector = 0)

> **Magnitude** (Click on choice.)

• **mg** • **T** • **N**

Think again. (Look at the hint.) <5>

Errors
2/2

Hint