

# **Problem Solving; Understanding and evaluating the many component skills, processes and beliefs.**

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**Wendy Adams**

*University of Colorado, Boulder*



# Introduction

- ➊ Most important aspect of University science education – **learn problem solving**
  - Science educators
  - Employers & Alumni



**What do we know about how to actually teach problem solving?**

**How can we measure it to know if our students are learning?**

**How might we teach them better?**

# Outline

- **Problem Solving**

- Knowledge, processes and beliefs

- **Research in Problem Solving**

- Physics, Psychology, Mathematics, Cognitive Science...

- **New approach to measure problem solving**

- Identification of nearly all specific components needed to solve any problem using a new instrument. (*Embedded data design - physics not required*)

- Comparison with results of a range of other problems (workplace to quantum mechanics).

# **Problem Solving:**

**"Problem solving is cognitive processing directed at achieving a goal when no solution method is obvious to the problem solver."** (Mayer, 1992)

- Definition based on the solver.
- Problem vs. Exercise

## **Problem:**

**"A problem arises when a living creature has a goal but does not know how this goal is to be reached. Whenever one cannot go from a given situation to the desired situation simply by action, then there has to be recourse to thinking. Such thinking has the task of devising some action, which may mediate between the existing and desired situations."** (Duncker, 1945)

# **Problem Solving Component Skills, Processes and Beliefs**

**Anything that can affect the subject's ability to solve the problem.**

**'Addition'**

**'Connects steps and Pieces'**

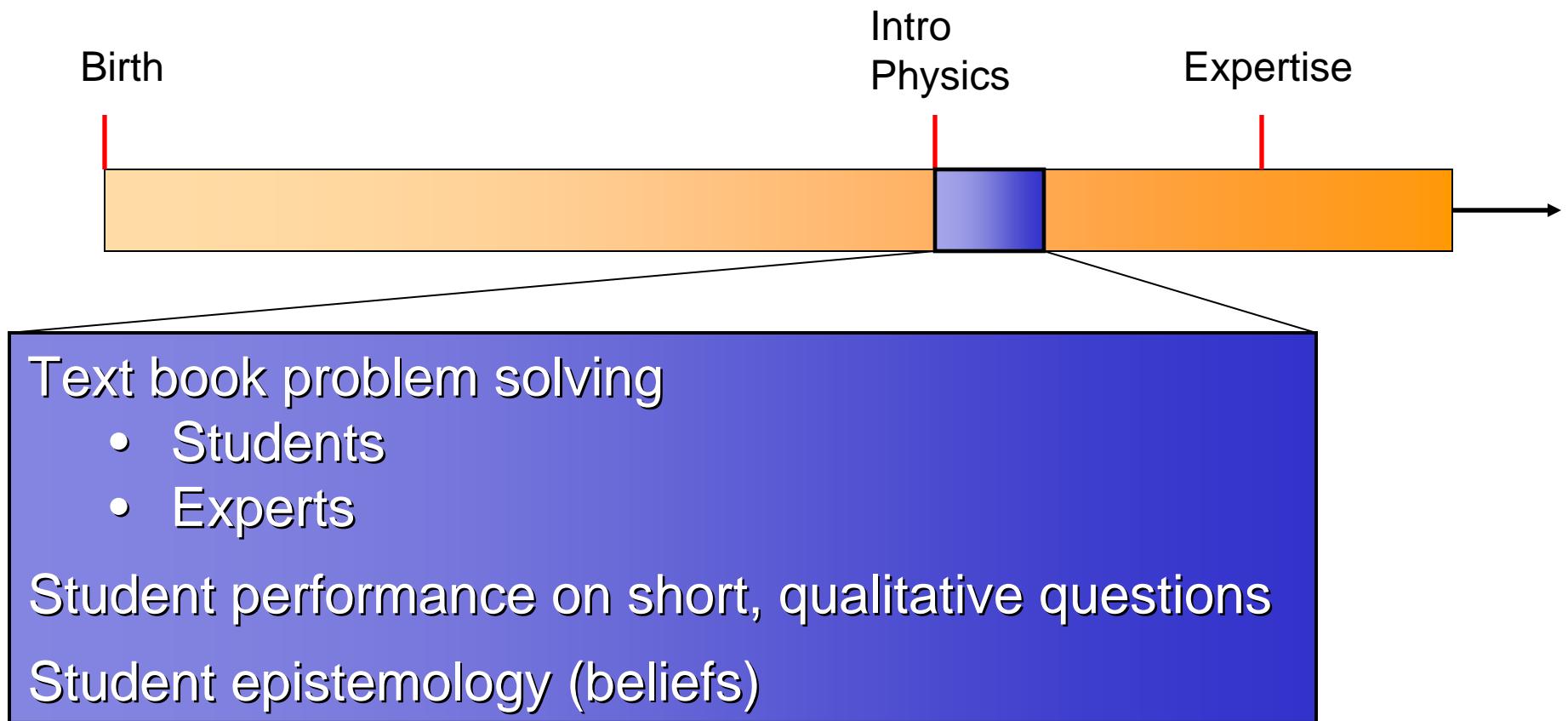
**'Creativity'**

**'Wants to succeed on "test"'**

# **Types of Knowledge and Cognitive Processes Involved in Problem Solving**

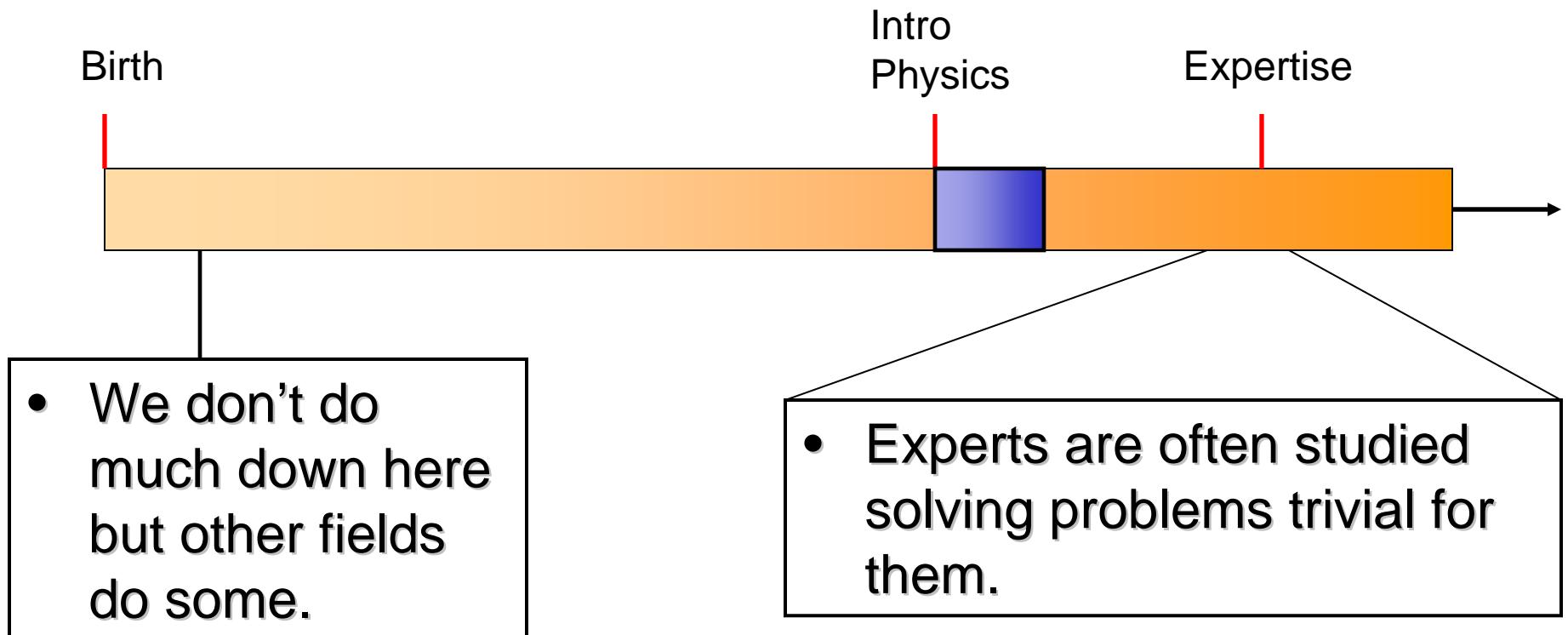
<b>Knowledge – have</b>		<b>Processes – do</b>
Adapted from Mayer and Wittrock (2006).		

# Field of Problem Solving Research

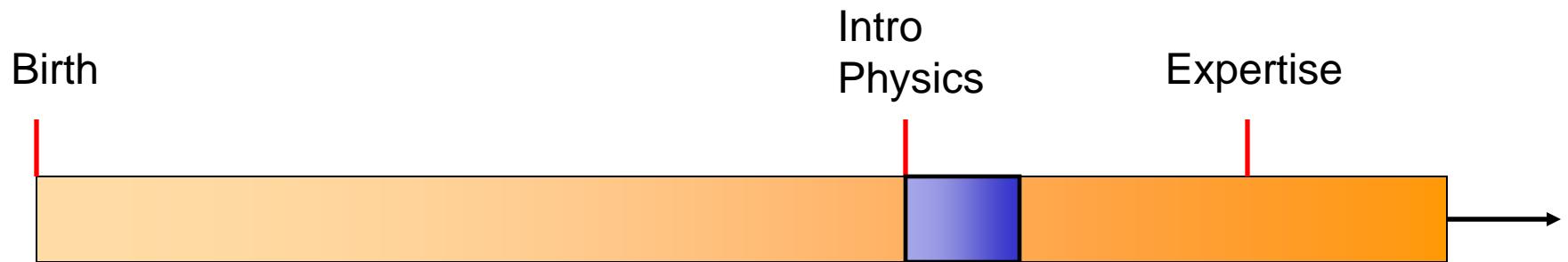


Timeline adapted from Sherin, 2007

# Field of Problem Solving Research



# Field of Problem Solving Research

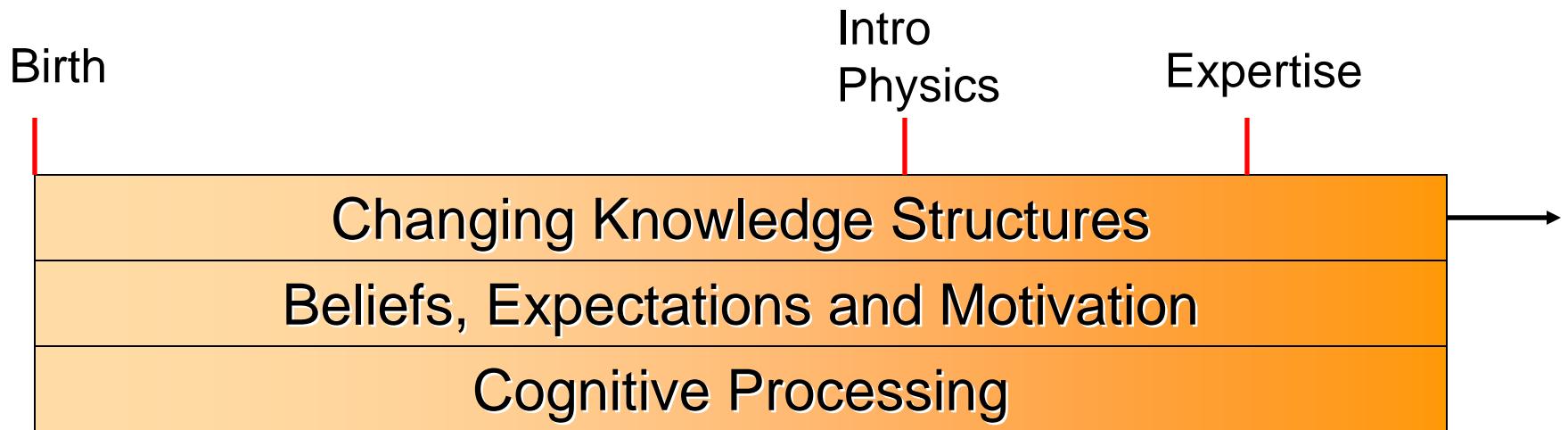


**As a result of limited studies....**

- Attempts to teach problem solving is predominantly centered on teaching the correct problem solving strategy
- Limited success

If we can make them act like expert problem solvers - then they will be experts.

# Field of Problem Solving Research



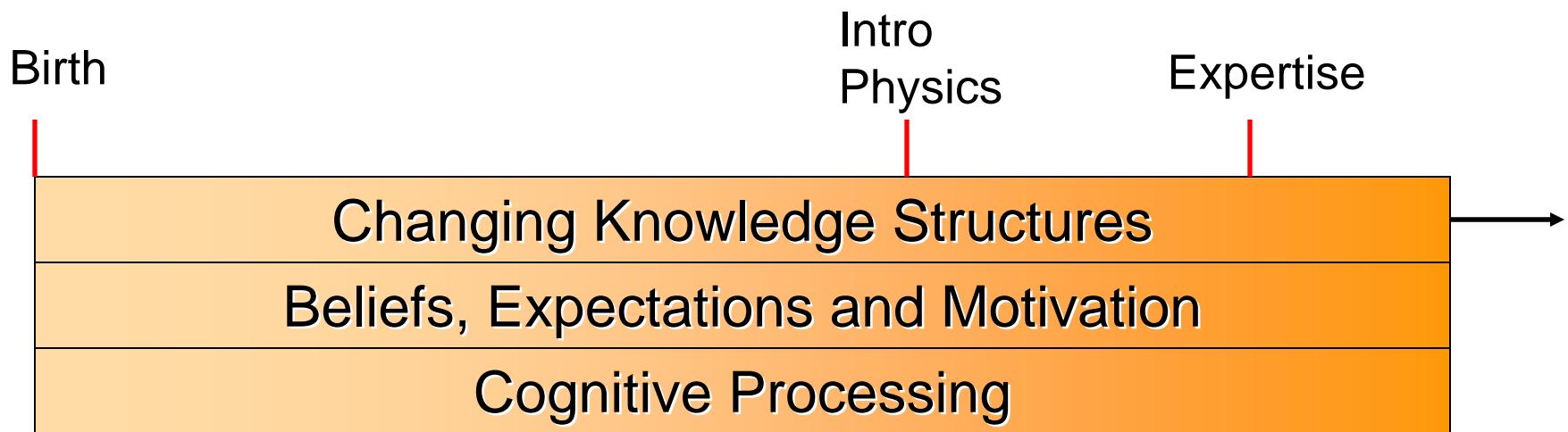
**Solving a problem requires some knowledge, even if it's in the form of a general strategy for analyzing situations and attempting solutions.**

**There have to be processes for operating on that knowledge to solve problems and answer questions.**

- “*...a failing student would express dismay since s/he had understood the way to solve the problem perfectly when I explained it in class.*  
*I had to point out that the exam did not test their understanding of my solution, but their ability to generate their own solution. This mismatch in processing is a common and underappreciated influence on transfer.”*

Ross 2007 PERC conference

# Field of Problem Solving Research

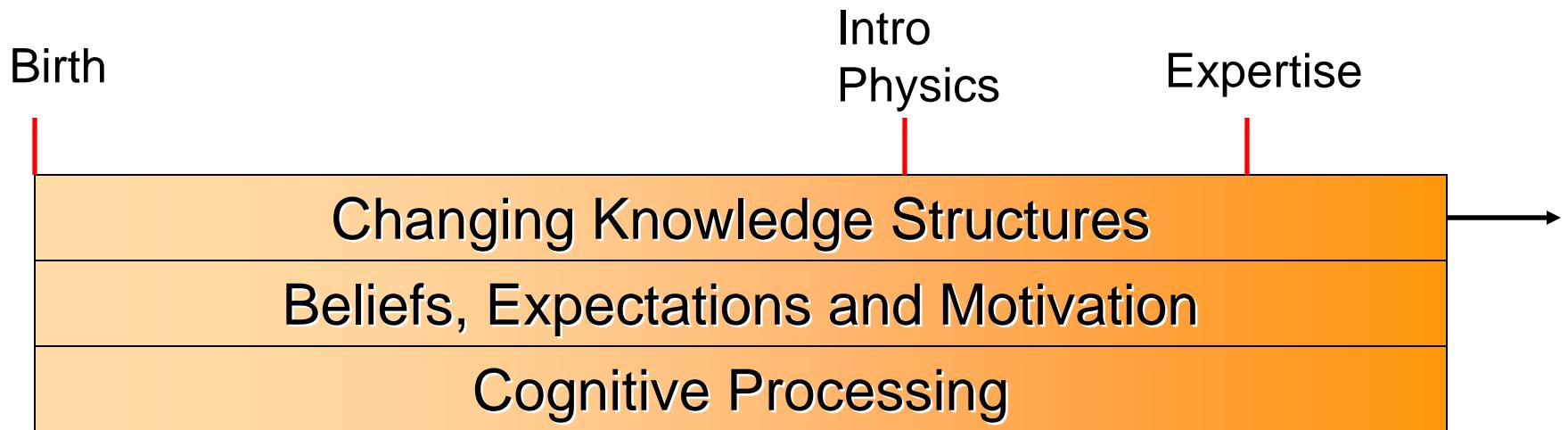


**Another outcome of limited studies...**

- Many researchers will say that problem solving skills do not transfer
- Others speak of general skills

**Assumptions are a result of inadequate studies and analysis tools.**

# Field of Problem Solving Research



**Toward a grand theory - We should look more broadly**

- Knowledge and processes throughout the life cycle
- Across a broader range of tasks
- Look to other fields
- Form and content at the “elemental” level

# Approach

**Develop a tool that identifies specific weaknesses in problem solving, in addition to strengths**



- How can we find out more than, “Did they solve the problem or not?”
  - A student could be expert like in many skills but one weakness can cause failure when solving a problem.  
For example: '**Newton's Laws**'
- How can **physics - free** measurements be made?
- Study a wide range of people, doing involved problems – specific modes of failure allow identification of specific components.

# Problem Solving Instrument

- **Base problem from the Jasper Woodbury Series\***

- Story opens with Larry teaching Emily how to fly his ultra-light plane.
- Jasper tells Emily and Larry about camping trip at Boone's Meadow 5 miles in.
- Jasper finds wounded Eagle
- Emily has complicated problem of planning best transportation considering route, payload, mileage and timing.
- The Solver is required to help Emily plan the rescue.



\*<http://peabody.vanderbilt.edu/projects/funded/jasper/>

# Problem Solving Instrument

- **Embedded data design** - Free of discipline specific content.
- Engaging real world scenario.
- It is a “problem” regardless of your content expertise.
- Identifies a student’s **skill set**. Strengths as well as weaknesses in 44 specific areas used in all types of problem solving.
- Two scripted interns solve the problem while you solve the problem. (adds task of analyzing interns as well)
- Written instrument takes about 1 hour



# Sample

## 7. How confident are you about your answer?

- a. Positive
- b. Pretty sure
- c. Think it's close
- d. Not sure at all



Do you think that means we have to count the gas in the tanks as part of the payload or maybe it only counts extra fuel that you take along?

Sara considers this for awhile.

That seems strange but he did say the payload includes fuel so I think we should count that. What does a full tank of gas weigh?



How should I know? It held 5 gallons, does that help?

## 8. Do you know what the gas weighs or how they could figure this out?

# Development

- **30 students interviewed while completing the evaluation tool and 16 written responses collected.**
  - Identify strengths and weaknesses in problem solving
  - Refine story and the questions
  - Variety of subjects
    - High school dropout, Elementary Ed. Majors, Non-science majors, physics/engineering majors and professors.



# Development

Does this tell us anything about how students solve science problems?

...Physics in particular?

# Comparison Problems

- Instructor and/or employer evaluation compared to evaluation tool interview results.



# Comparison Problems

- Mechanics problem solving compared to evaluation tool written results with 5 students.

*Given height of the pyramid,  
dimensions of a block,  
horse power of a man,  
time allotted to build,*

*How many men were  
required to build the Great  
Pyramid of Giza?*



University of Maryland Physics Education Research Group (2002).  
Activity-Based Physics (ABP) Alternative Homework Assignments.  
<http://www.physics.umd.edu/perg/abp/aha/index.html>

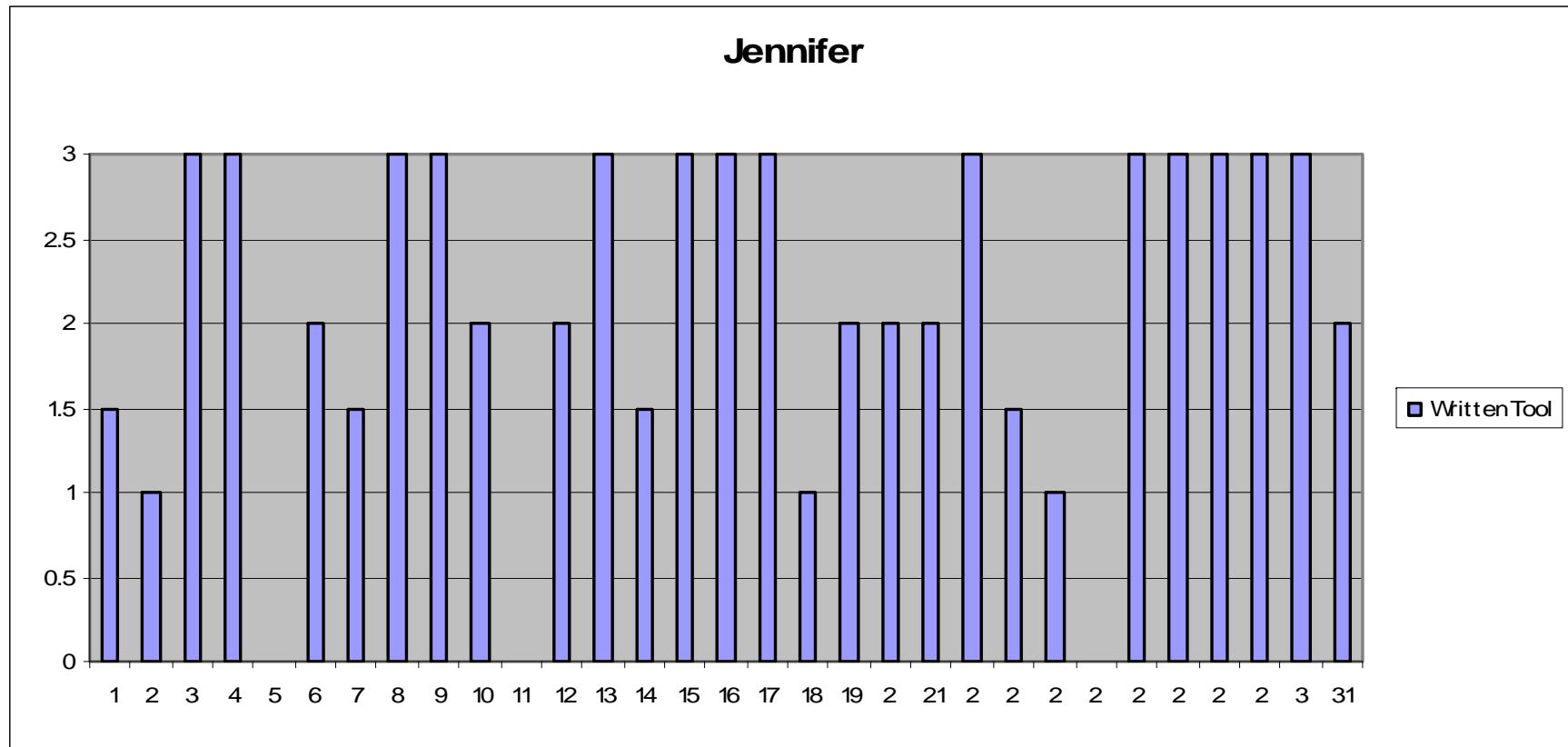
# Results



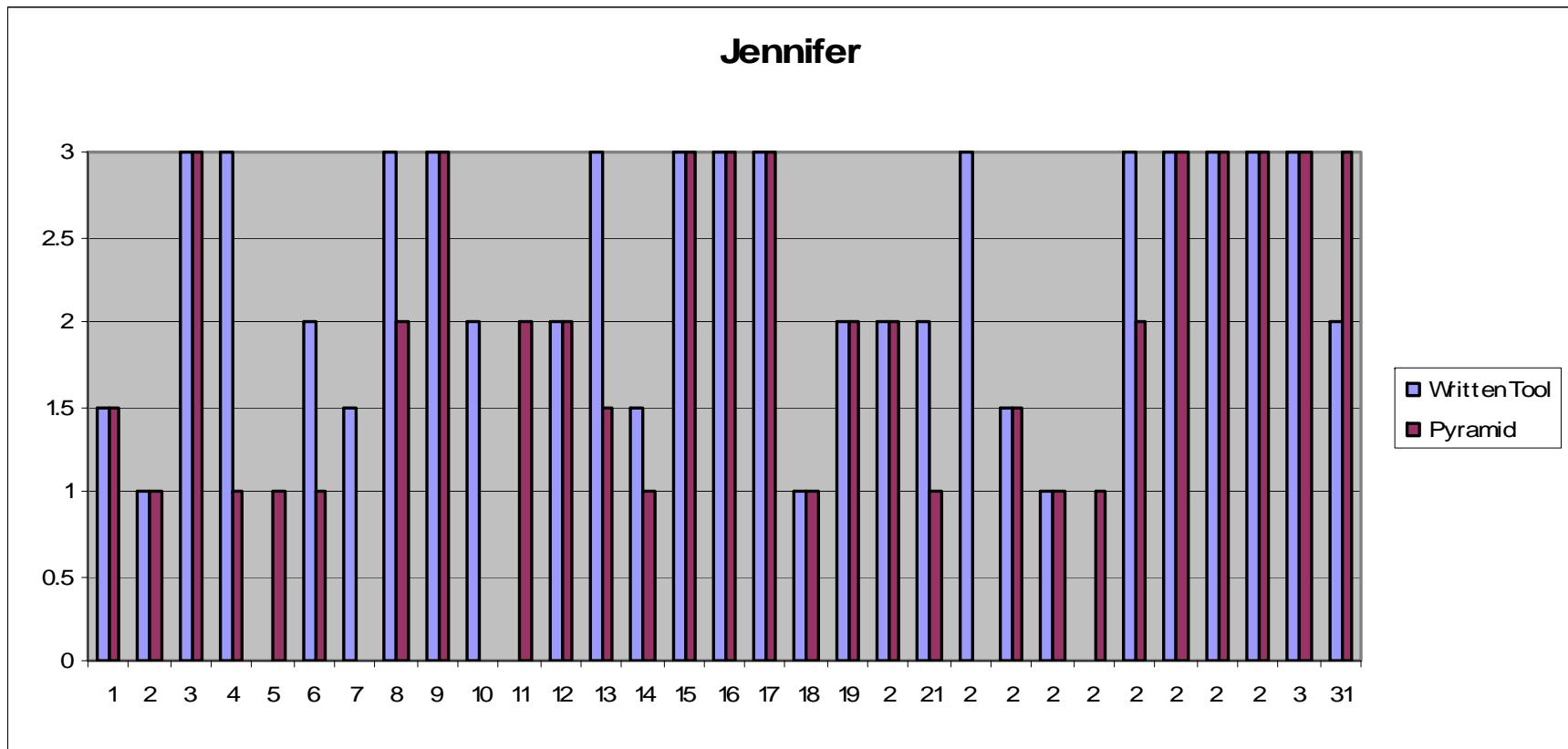
- Written version of evaluation tool graded blind two months later
- 3 point scale used for grading of rubric.

All students easily identified and  
matched up.

# Results



# Results



# Results

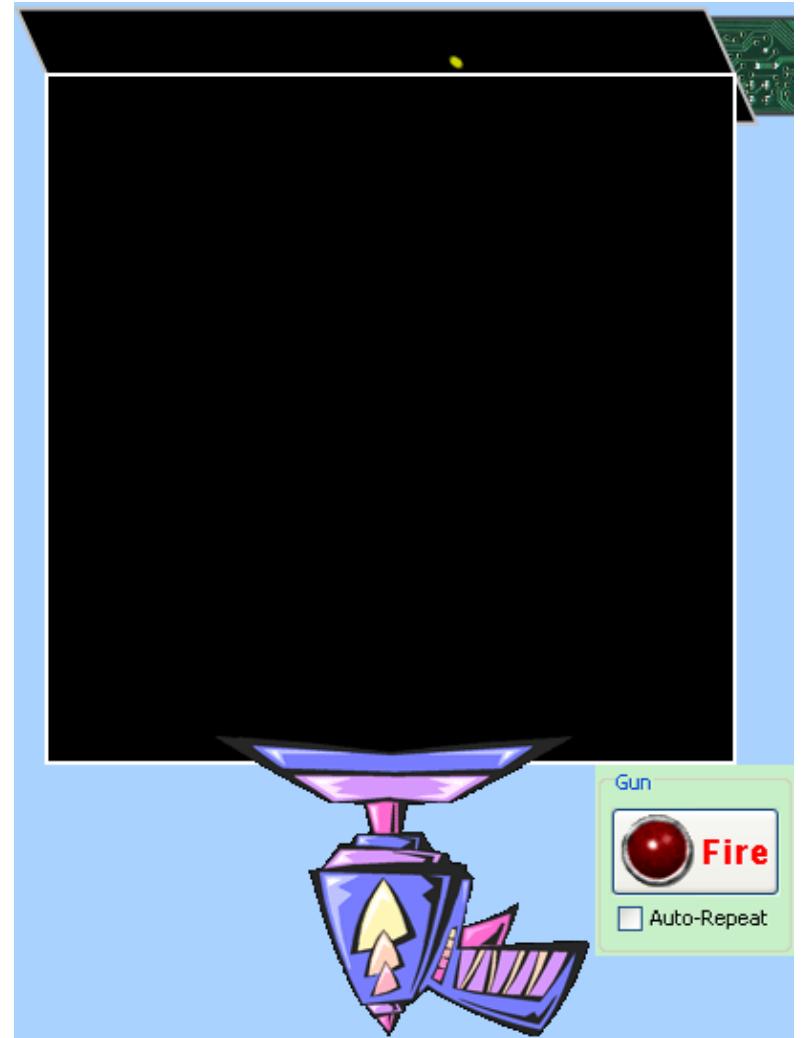


	Skills scored by both	# scores matched
Female #1	19	19
Female #2	17	16
Female #3 (incomplete)	12	11
Male #1	18	17
Male #2	16	12

# Comparison Problems

**Quantum Mechanics problem solving compared to evaluation tool results of 5 students.**

- Independent interviewer scored physics and Engineering students while solving a series of Quantum Mechanics' problems.
- *Suppose you are shooting photons at a screen one at a time and you see a dot appear on the screen as in the picture to the right. Where was that photon the instant before it hit the screen?*
- Refined Rubric

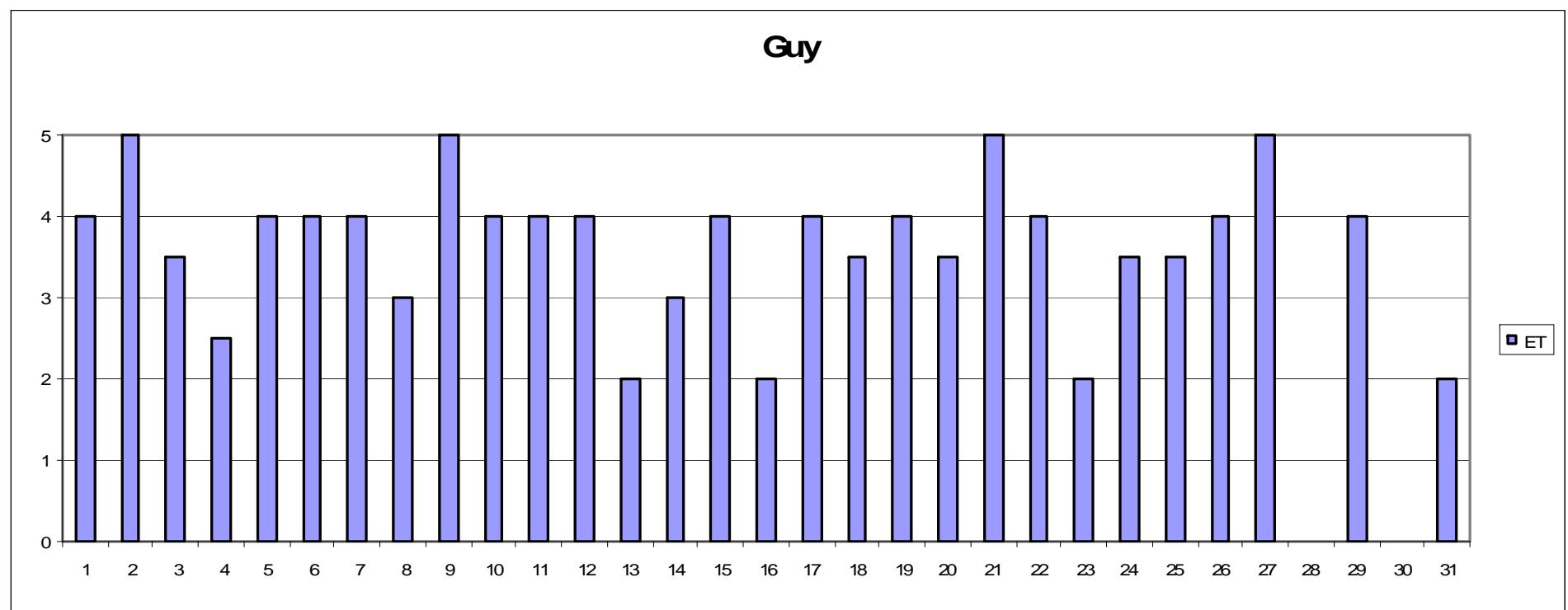


[PhET.colorado.edu](http://PhET.colorado.edu)

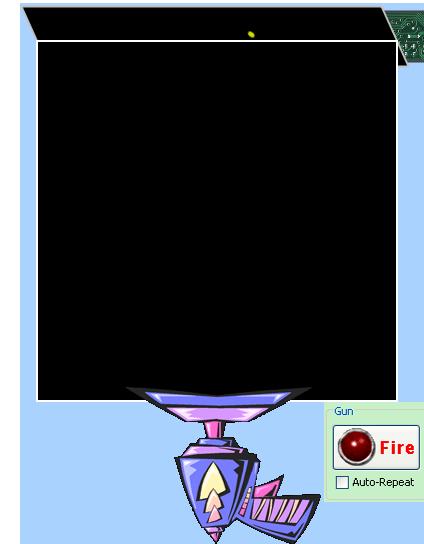
# Results



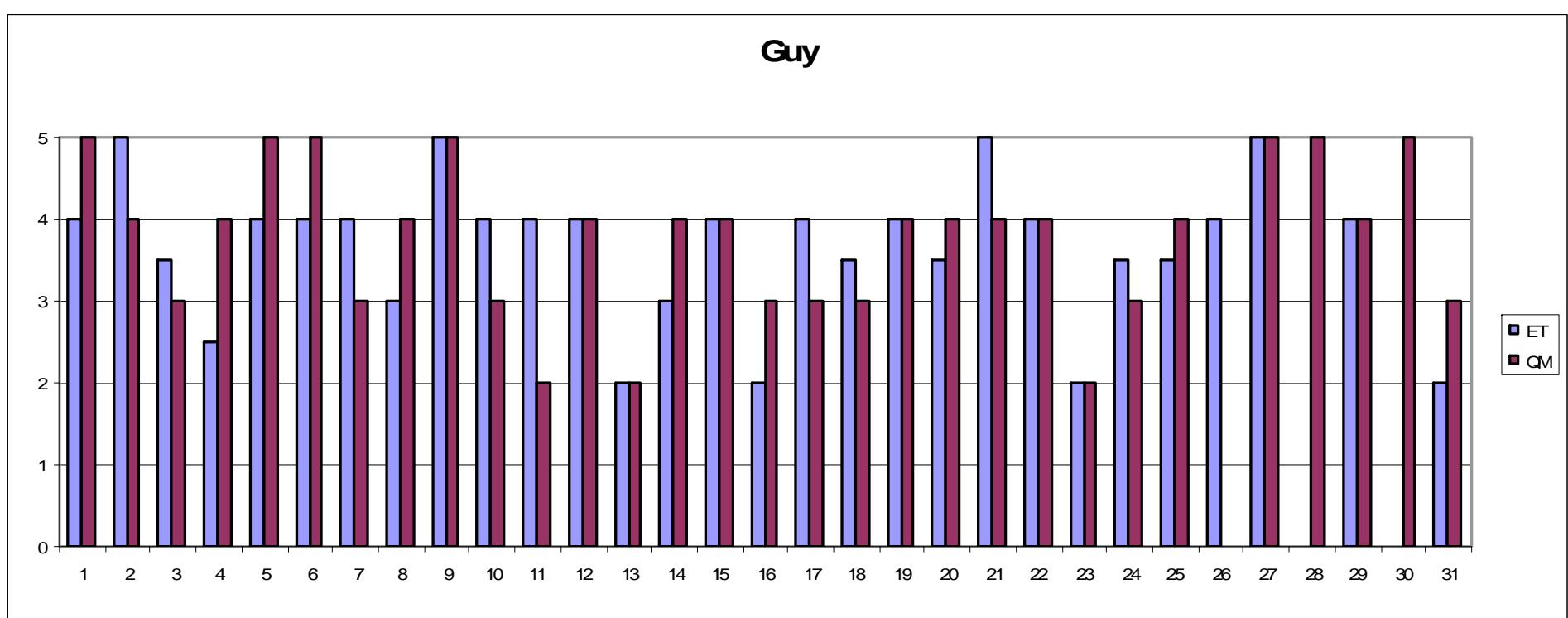
**Guy**



# Results



**Guy**



# Results



	Skills scored by both	# scores matched
Female #1	31	28
Female #2	31	29
Male #1	31	20
Male #2	31	30
Male #3	31	28

# Results

- Students bring the **same skill set** to very different types of problem solving.
- Independently confirmed
  - Skills used to solve trip planning scenario are the same as those used to solve:
    - Quantum Mechanics Problems
    - Mechanics Problem
- Empirical categorization of problem solving component skills, processes and beliefs.
- Problem Solving Evaluation Tool
  - Addresses specific component skills needed to solve physics problems
  - Avoids the typical pitfalls of students getting ‘stuck’ or ‘knowing’ the solution.



# Problem solving skills, process, beliefs

Knowledge – have	Beliefs, Expectations & Motivation	Processes – do
<ul style="list-style-type: none"><li>▪ Math - basic add/sub/mult/div</li><li>▪ Math - equation formation</li><li>▪ Reading comprehension</li><li>▪ Spatial - mapping</li><li>▪ Previously known facts</li><li>▪ Real World knowledge</li><li>▪ Knowledge of own Strengths</li><li>▪ Knowledge of own Weaknesses</li><li>▪ Number Sense</li></ul>	<ul style="list-style-type: none"><li>▪ Confidence</li><li>▪ Attribution (takes responsibility)</li><li>▪ Judgment of info based on the source</li><li>▪ Wants to solve the problem for self</li><li>▪ Wants to solve the problem for interviewer</li><li>▪ Wants to succeed on the "test"</li><li>▪ Interested in the context of the problem</li><li>▪ Enjoyed solving the problem</li><li>▪ Enjoyed analyzing interns</li></ul>	<ul style="list-style-type: none"><li>▪ Acquires Info 1<sup>st</sup> time through</li><li>▪ Plan ideas (What - ask questions)</li><li>▪ Plan way to get answer (How)</li><li>▪ Plan - big picture (Visualization)</li><li>▪ Keep problem framework in mind</li><li>▪ Connect steps and pieces</li><li>▪ Check calculations of others</li><li>▪ Aware of how others helped</li><li>▪ Meta-process - step outside of problem solving to see if own actions are useful.</li></ul>

# Problem solving skills, process, beliefs

Knowledge – have	Beliefs, Expectations & Motivation	Processes – do
<ul style="list-style-type: none"><li>▪ Estimation</li><li>▪ Ability to analyze interns</li></ul>	<ul style="list-style-type: none"><li>▪ Enjoyed complete experience</li><li>▪ Real life vs. student</li><li>▪ Careful/Thorough</li></ul>	<ul style="list-style-type: none"><li>▪ Skepticism</li><li>▪ Estimation</li><li>▪ Creativity</li><li>▪ Adaptability (shifts direction easily)</li><li>▪ Can throw out useless info</li><li>▪ Judgment of reasonable issues</li><li>▪ Judgment of importance of values (is it material)</li><li>▪ Tie in personal experiences</li><li>▪ Tie in info provided by another</li><li>▪ Scientific Process (each step based on evidence not by gut feeling)</li><li>▪ Remember previously noted facts</li><li>▪ Remember what s/he has calculated or reasoned.</li></ul>

# Example of Rubric

## ● **Skepticism**

level

- 1 - Believes whatever is told to them. If the character says something different from what they've already figured out, will immediately question themselves and assume they must be wrong and the outside person correct. Will really struggle to find why the character is right and question self before anything written even from a made up intern in evaluation tool.
- 3 - Selective about what information they trust; however, base this decision on source or maybe reasonableness rather than content.
- 5 - Always checks new information based on its reasonableness as well as looking for another source to corroborate the information.

# Example Data

## Quantum Mechanics Interviewer:

*“she seemed to view learning [as] how to accept every weird thing we told her... she thought the first step was to accept things and the second step was to try to understand them. She always rethought her ideas when another student suggested something, although she maintained enough skepticism to recognize that other students were often wrong.”*

## Problem Solving Interviewer:

*“Always had a knee jerk response which was not always good but then on her own she considers carefully and comes up with the right answer. ...she'll consider whatever is thrown out there, decisions are based on the most logical answer. If a suggestion does not make sense after careful consideration, she holds onto her beliefs. Very reliable”*

# Skills in the classroom



Typical homework problems require:

- Knowledge of the content (Newton's Laws, algebra, ...)
- Plan way to get answer (How)
- Estimation
- Remember what s/he has calculated or reasoned
- Wants to solve the problem (for self, for grade, ...)
- Careful/Thorough
- Confidence

In groups:

- Check calculations of others
- Tie in info provided by another
- Adaptability (shift direction easily)

# Skills in the classroom



## Show Stoppers:

- Content Knowledge – (**Newton's Laws**)
- Wants to solve the problem (self, grade, ...)
- Attribution (takes responsibility for their actions)
- Plan way to get answer

## Compensation:

- Careful/Thorough helps compensate for weak content, planning, Remember what s/he has calculated or reasoned.
- Meta-processing helps compensate for weak planning

# Skills in the classroom



**Not** needed with typical homework problems:

- Picking up information the first time through
- Planning ideas (Creating questions)
- Visualizing the problem
- Remember previously noted facts
- Keep problem framework in mind
- Can throw out useless information
- Judgment of reasonable issues
- Creativity
- Skepticism
- Ties in personal experiences
- Student vs. Real world

# Skills in the classroom



**Not** needed with typical homework problems

- **Picking up information the first time thru**
  - quite important in real life but almost never required in school.
- **Skepticism**
  - Discouraged by the typical environment because it competes with another important lesson, do what your teacher tells you.
- **Visualize the Problem**
  - Some problems do require this but are rare. Most are not involved enough to require visualization for solution.
  - Students are often told they should make a diagram; however, it is a meaningless exercise to them when this is unnecessary for finding a solution.

# Skills in the classroom

**Not** needed with typical homework problems



- **Planning ideas (Creating questions)**
  - This is a debilitating weakness in any work environment that requires leadership or independent work; however, it is not required with most problems where the problem is clearly laid out.
  - Emphasis on group work also allows a person who has poor skills in this area to do well in school without ever using this skill.

# Skills in the classroom



We teach ... unknowingly

- Ability to analyze interns
  - Translates to student analyzing the instructor.
  - Quite often learning all the material in a class is an insurmountable task; however, learning the material that is important to your instructor is not.
  - Once a student learns enough about the instructor to determine what to expect on the exams, their attention can be focused accordingly.
  - Similarly, an employee that has the ability to analyze his boss, customers and clients can be crucial.

# Conclusions

- Previous work studied a very limited population solving text-book type problems.
- I evaluated a wide range of people solving in-depth problems.
- Strengths and weaknesses identified with this one trip planning scenario, are the same for each person in a wide range of tasks. (from workplace to quantum mechanics)
- Itemization of specific skills, beliefs and processes useful for thinking about how to teach problem solving.

