Ph.D. Dissertation Defense

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An Explanatory Model of Physics Faculty Conceptions about the Problem-Solving Process*

Hsia-Po Vincent Kuo

Patricia Heller & Ken Heller
University of Minnesota
Charles Henderson
Western Michigan University
Edit Yerushalmi
Weizmann Institute

http://groups.physics.umn.edu/physed/

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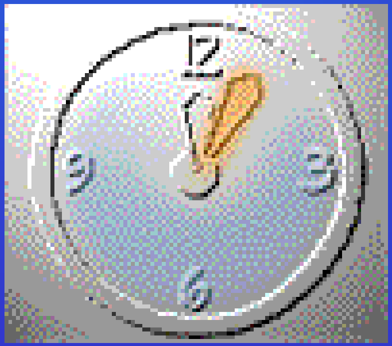
Outline of talk

1. Putting the study into perspective
2. Rationale
3. Background – Initial Explanatory Model
3. Current Study – Refined Explanatory Model
4. Summary



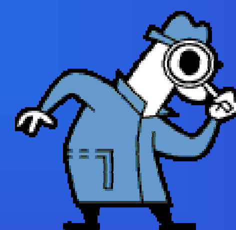
Grand Scheme of Things …

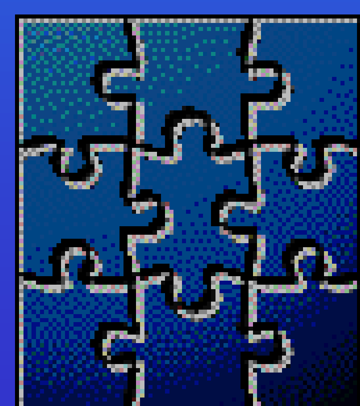
Curricular Material that physics instructors will adopt for their introductory calculus-based physics courses

Instructors' conceptions about various elements in the educational environment of introductory calculus-based physics

Explanatory Model of instructors' conceptions about the teaching and learning of problem solving

Instructors' conceptions about the problem-solving process





Rationale

Transformation Process

Initial State of Learner → **Traditional Instruction** (i.e., teacher-centered lecture, verification labs, textbook problems) → **Desired Final State of Learner**

Not very effective at accomplishing certain desired final states

Instructor

Van Heuvelen (1991), *AJP,* 59(10)

Chi, Feltovich, & Glaser, 1981; Maloney, 1994; Mazur, 1997; McDermott, 1993; Van Heuvelen, 1991

Contributions of Physics Education

Transformation Process

Initial State of Learner

Research-Based Instruction
(e.g., interactive engagement, problem-solving labs, context-rich problems)

Desired Final State of Learner

Overview, Case Study
(Van Heuvelen et. al.)

Cooperative Group Problem Solving
(Heller et. al.)

Peer Instruction
(Mazur et. al.)

Personal Assistants for Learning
(Reif et. al.)

Instructor

SCALE-UP
(Beichner et. al.)

Minds on Physics
(Mestre et. al.)

Tutorials
(McDermott et. al.)

Workshop Physics
(Laws et. al.)

Why don't more instructors use research based curricular materials?

Our hypothesis: The available curricular materials are not consistent with instructor's conceptions

It is important to either:

1. **Change the curricular materials**
   - Curricular materials built on instructors' conceptions are more likely to be used and used appropriately
2. **Change the instructor conceptions**

   We know from students:
   - Changing conceptions is hard

In either case it is first necessary to determine what these conceptions are

Focus of This Study

Instructor Conceptions

1.Subject (i.e., conceptions about the subject they are teaching)
2.Teaching and Learning (e.g., pedagogical knowledge, orientation towards teaching)
3.Context (e.g., conceptions of student capabilities, conceptions of administrative constraints)

Instructor conceptions about the problem-solving process

Influence*

1. How they model/explain problem solving to students
2. How they expect students to solve problems
3. How they expect students to learn how to solve problems
4. Their attitudes towards curricular materials

*Prosser & Trigwell (1999), Understanding Learning and Teaching

Why Problem Solving?

- **Physics Course** (e.g., Donald, 1993)
  - Key element
  - Goal
- **Constituent Departments** (e.g., survey conducted by PERG @ UMn)
  - Goal: learn generalized problem-solving skills within the context of physics
- **Life**
  - Ability to solve problems in new situations or under new constraints
  - Hallmark of successful scientists and engineers

Overview of Program

Exploratory Study –
Small Sample

Initial
model based
on 6 RU instructors

Refine and expand the
initial model based on 24
interviews with instructors from
different institutions in the state of MN

Determine the distribution of conceptions
among instructors using a larger national sample

Sharpen understanding using an international sample

Focused Study –
Large Sample

The Interview Tool

To investigate instructor conceptions, we developed a 1½ - 2 hour interview based on instructional artifacts:

1st) 3 Instructor solutions: varied in the details of their **explanation**, **physics approach**, and **presentation structure**

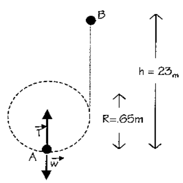
2nd) 5 Student solutions: based on actual final examination solutions at the University of Minnesota to represent **features of student practice**

3rd) 4 Problem types: represent a range of the **types of problems used** in introductory physics courses

All artifacts were based on **one problem** -- instructors were given the problem and asked to solve it on their own before the interview

The Interview Tool - IS

Instructor solution I



The tension does no work

Conservation of energy between point A and B

$Mv_A^2/2 = mgh$

$V_A^2 = 2gh$

At point A, Newton's 2nd Law gives us:

$\vec{T} - \vec{w} = m\vec{a}$

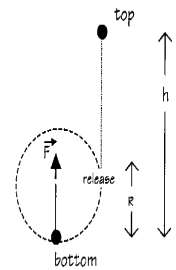
$T - w = mv_A^2/R$

$T = 18_N + 2 \cdot 18_N \cdot 23_m / .65_m = \boxed{1292N}$

Instructor solution II

Known
- $w = 18N$ = weight of stone
- $R = 0.65m$
- $h = 23m$
- $v_t = 0$ = velocity at top

Unknown
- $v_r = ?$ = velocity at release
- $v_b = ?$ = velocity at bottom
- force my hand exerts = $F = ?$



Step 1) Find v_r needed to reach h

$E_i = E_f$

$E_{release} = E_{top}$

$PE_{release} + KE_{release} = PE_{top} + KE_{top}$

$\cancel{m}gR + \cancel{m}v_r^2/2 = \cancel{m}gh + \cancel{m}v_t^2/2$ (0)

$v_r^2 = 2g(h - R)$

Conservation of energy for the stone earth system, since no external forces.

Note: you could also choose other systems.

KE of earth estimated to be 0

You could also use kinematics to find v_r

Step 2) Find v_b needed to have v_r at release

$E_{bottom} = E_{release}$

$PE_{bottom} + KE_{bottom} = PE_{release} + KE_{release}$

$mg0 + \cancel{m}v_b^2/2 = \cancel{m}gR + \cancel{m}v_r^2/2$

Using v_r from above:

$V_b = [2gh]^{1/2}$

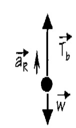
Conservation of energy for the stone earth system. Since $T \perp v$ in circular path, T does no work.

Step 3) Find T_b, tension at bottom, needed for stone to have v_b at bottom

$\sum \vec{F} = m\vec{a}$

$\sum F_R = ma_R$

$T_b - w = m\,v_b^2/R$



Free body diagram

To relate the forces to velocity we can look at the radial component, and use $a_R = v^2/R$.

Using v_b from above:

$T_b - w = 2\,mgh/R$

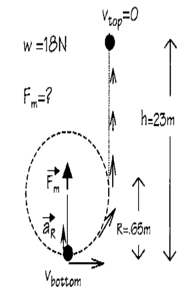
$T_b = w + 2\,w\,h/R = 18 + 2\;18\;23/.65 = \boxed{1292N}$

T_b equals F, the force my hand exerts, for a massless string

Instructor solution III

Approach:

I need to find F_m, force exerted by me. I know the path, h (height at top) and v_t (velocity at top)



A) For a massless string $F_m = T_b$ (T_b-Tension at bottom)

B) I can relate T_b to v_b (velocity at bottom) using the radial component of $\sum \vec{F} = m\vec{a}$, and radial acceleration $a_R = v^2/R$, since stone is in circular path

C) I can relate v_b to v_t using either i) energy ii) Dynamics and kinematics

ii) Messy since forces/accelerations change through the circular path

i) I can apply work-energy theorm for stone. Path has 2 parts:

first - circular, earth and rope interact with stone,

second - vertical, earth interacts with stone

In both parts the only force that does work is weight, since in first part hand is not moving $\Rightarrow \vec{T} \perp \vec{v} \Rightarrow \vec{T}$ does no work.

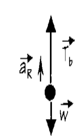
Execution:

B) Relate T_b to v_b

$\sum \vec{F} = m\vec{a}$

$\sum F_R = ma_R$

$T_b - w = m\,v_b^2/R$



C) Relate v_b to v_t

Work = ΔKE

For constant force

$\vec{F} \cdot \vec{d} = KE_f - KE_i$

$F_y d_y = KE_{top} - KE_{bottom}$

Substituting C) into B)

$T_b - w = 2\,w\,h/R$

$F_m = T_b = w + 2\,w\,h/R$

$= 18 + 2\;18\;23/.65$

$= \boxed{1292N}$

N=N m/m units O.K.

Large compared to weight, but stone needs to travel up large distance

Check limits: $T_b \uparrow$ as $R \downarrow$, for smaller circle I'll need bigger force, reasonable

The Interview Tool - SS

Student Solution A

Student Solution A

$\frac{V^2}{R} = a = \frac{F}{m}$ $\qquad \frac{2\pi R}{T} = V$

$a = \frac{\left(\frac{2\pi R}{T}\right)^2}{R} = \frac{4\pi^2 R}{T^2}$

$V = \sqrt{Ra}$

$y = y_0 + vt + \frac{at^2}{2}$

$= 0.65 + \sqrt{Ra}\,t + \frac{at^2}{2}$

$\cancel{V^2}^{\to 0} - V_0^2 = -2g\Delta y$

$V_0 = \sqrt{2g\Delta y} = \sqrt{Ra}$

$\frac{2g\Delta y}{R} = a = \frac{F}{m}$

$F = \frac{2mg\Delta y}{R} = \frac{2\cdot 18\cdot(23-0.65)}{0.65} = 1237.846N$

uses $V_{release}$ instead of V_{bottom}

Does not sum forces

Student Solution B

Student Solution B

v_0 T T mg

This is a centripetal force problem $\Rightarrow F = m\frac{v^2}{R}$

Free Fall:

$\overset{=0 \text{ at max. height}}{v_y} = v_0 - gt$

$gt = \frac{v_0}{g}$

$t = \frac{v_0}{g}$

$\Delta y = y_0 + v_0 t - \frac{1}{2}gt^2$

$\Delta y = y_0 + v_0\left(\frac{v_0}{g}\right) - \frac{1}{2}g\left(\frac{v_0}{g}\right)^2$

$\Delta y = y_0 + \frac{v_0^2}{g} - \frac{1}{2}\frac{v_0^2}{g}$

$\Delta y = \frac{(y_0 - \frac{1}{2})v_0^2}{g}$

uses Δy instead of y

makes math error

$\frac{\Delta y g}{(y_0 - \frac{1}{2})} = v_0^2$

$T = F = ma = \frac{m v_0^2}{R}$

$= \frac{mg\Delta y}{(y_0 - \frac{1}{2})R}$

$= \frac{18\cdot 22.65}{(.65 - \frac{1}{2})(.65)} = 4182N$

Force Exerted by me

Does not sum Forces

uses $V_{release}$ instead of V_{bottom}

Student Solution C

Student Solution C

$V_t = 0$ $\quad h \quad R \quad V_r \quad V_b \quad mg \quad T$

$V_t = 0$

$V_r = ?$

$V_b = ?$

$T = ?$

$mg = 18N$

$h = 23m$

$R = 0.65m$

Find velocity to reach height (free fall)

$V^2 - V_0^2 = 2a(y - y_0)$

$\cancel{0 - V_r^2 = 2(-g)(h)}$

$0 - V_r^2 = 2(-g)(h-R)$

$V_r = \sqrt{2g(h-R)}$

$= \sqrt{2\cdot 9.8\,m/s^2\cdot(23-0.65)m}$ $\qquad \sqrt{m/s^2\cdot m} = m/s$

$= 20.9\,m/s$

It can't be that $V_r = V_b$ but I don't know how to relate them. If $V_r = V_b$, then:

Find force

$\Sigma\bar{F} = m\bar{a}$

$T - mg = ma_c$ $\qquad N + \frac{N}{m/s^2}\cdot\frac{m^2/s^2}{m} = N$

$T = mg + \frac{mv_r^2}{R} = 18N + \frac{\frac{18N}{9.8\,m/s^2}(20.9\,m/s)^2}{0.65m}$

Force exerted by me $= 1256N$

Looks large, but stone needs to go up far

uses $V_{release}$ instead of V_{bottom}

Student Solution D

Student Solution D

$V = 0$

$h = 23m$

V

$.65m$

Energy conservation between top and release

$\frac{1}{2}mv^2 = mg\Delta h$

$v^2 = 2gh$

$V = \sqrt{2(-9.8)23}$

$V = 21.2$

uses h instead of h-R

makes sign error

changes sign

Between release and bottom $T \perp v$ so no work done $\therefore$ Energy is conserved and velocity is the same

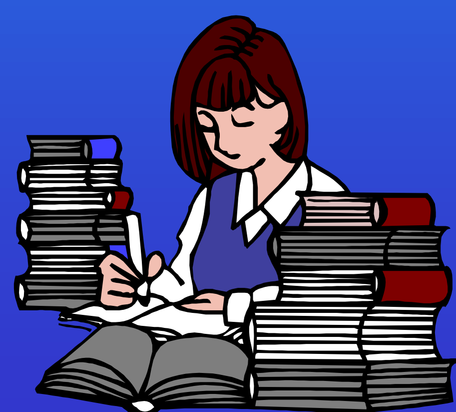
$\Sigma\bar{F} = m\bar{a}$

$T - mg = \frac{mv^2}{R}$

$T = 18 + \frac{\frac{18}{9.8}\cdot 21.2^2}{.65}$

$= 1292N$

uses $V_{release}$ instead of V_{bottom}



Student Solution E

Student Solution E

$V^2 = 2gh$

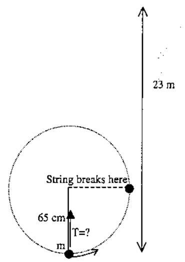
$F - mg = \frac{m2gh}{R}$

$F = 18 + \frac{2\cdot 18\cdot 23}{.65} = 1292N$

The Interview Tool - P

Problem A **Problem A**

A 1.8 kg mass is attached to a frictionless pivot point and is moving in a circle at the end of a 65 cm string. The string breaks when the mass is moving directly upward and the mass rises to a maximum height of 23.0 m. What is the tension in the string one-quarter turn before the string breaks? Assume that air resistance can be neglected.



A) What velocity, v_1, must the stone have when released in order to rise to 23 meters above the lowest point in the circle?

B) What velocity, v_o, must the stone have when it is at its lowest point in order to have a velocity v_1 when released?

C) What force will you have to exert on the string at its lowest point in order for the stone to have a velocity v_o?

Problem B **Problem B**

You are whirling a stone tied to the end of a string around in a vertical circle having a radius of 65 cm. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height of 23 meters above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected. The stone weighs 18 N.

A) 1292 N
B) 1258 N
C) 1248 N
D) 1210 N
E) None of the Above

Note: The choices are based on common student problems.

Problem C **Problem C**

You are working at a construction site and need to get a 3 lb. bag of nails to your co-worker standing on the top of the building (60 ft. from the ground). You don't want to climb all the way up and then back down again, so you try to throw the bag of nails up. Unfortunately, you're not strong enough to throw the bag of nails all the way up so you try another method. You tie the bag of nails to the end of a 2 ft. string and whirl the string around in a vertical circle. You try this, and after a little while of moving your hand back and forth to get the bag going in a circle you notice that you no longer have to move your hand to keep the bag moving in a circle. You think that if you release the bag of nails when the string is horizontal to the ground that the bag will go up to your co-worker. As you whirl the bag of nails around, however, you begin to worry that the string might break, so you stop and attempt to decide before continuing. According to the string manufacturer, the string is designed to hold up to 100 lbs. You know from experience that the string is most likely to break when the bag of nails is at its lowest point.

Problem D **Problem D**

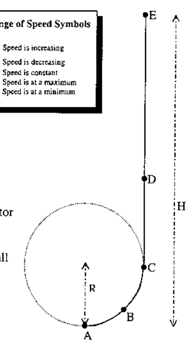
You are whirling a stone tied to the end of a string around in a vertical circle of radius R. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height, H, above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected.

A) For each point labeled in the diagram, circle the symbol(s) that describe how the speed of the stone is changing.

Point	Change in Speed
A	↑ ↓ = max min
B	↑ ↓ = max min
C	↑ ↓ = max min
D	↑ ↓ = max min
E	↑ ↓ = max min

Change of Speed Symbols

↑	Speed is increasing
↓	Speed is decreasing
=	Speed is constant
max	Speed is at a maximum
min	Speed is at a minimum



B) At each point on the diagram, draw and label a vector representing the acceleration of the stone.

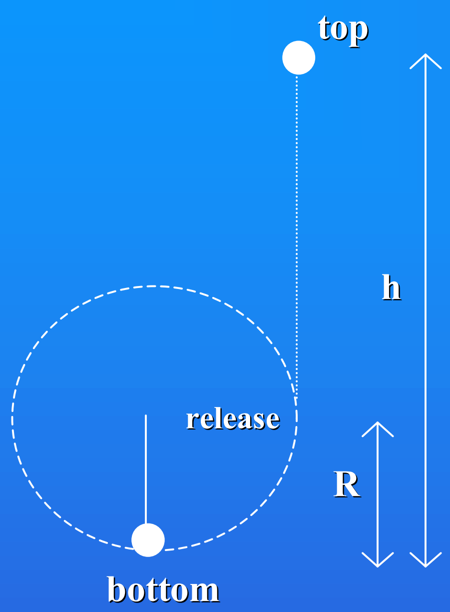
C) At each point, draw and label vectors to represent all of the forces acting on the stone.

Problem Used in the Interview

You are whirling a stone tied to the end of a string around in a vertical circle having a radius of 65 cm. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a **maximum height of 23 meters** above the lowest point in the circle. In order to do this, **what force will you have to exert on the string** when the stone passes through its lowest point one-quarter turn before release? **Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected.** The stone weighs 18 N.

Final examination question (Fall, 1997)

An Expert Solution



No work is done by string (since $\boxed{T \perp \upsilon}$), so all work is done by gravity. Using conservation of energy between bottom and top:

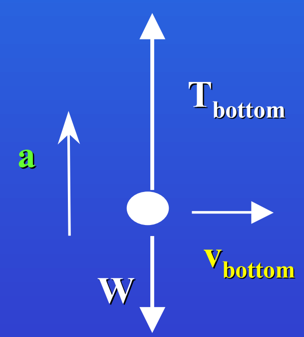
$$\frac{1}{2} m v_{bottom}^2 = mgh \longrightarrow v_{bottom}^2 = 2gh$$

Using Newton's 2nd Law at the bottom

$$T_{bottom} - mg = m\frac{v_{bottom}^2}{R} \longrightarrow T_{bottom} = m(g + \frac{v_{bottom}^2}{R})$$

$$T_{bottom} = m\,(g + \frac{2gh}{R})$$

$T_{bottom} = 1292\ N$



Free body diagram at bottom

Selecting Instructors for Interviews

Physics instructors in Minnesota (~107 meet selection criteria):

- taught introductory calculus-based physics course in the last 5 years (conducted in Spring of 2000)
- could be visited and interviewed in a single day

Sample Randomly Selected:

30 instructors

(From 35 contacted, 5 declined to be interviewed)

Roughly evenly divided among:

1) Community College (CC) N = 7
2) Private College (PC) N = 9
3) State University (SU) N=8
4) Research University (RU) N = 6

Interviews were videotaped and the audio portion transcribed:

~ 30 pages of text/interview

Overview of Program

Exploratory Study – Small Sample

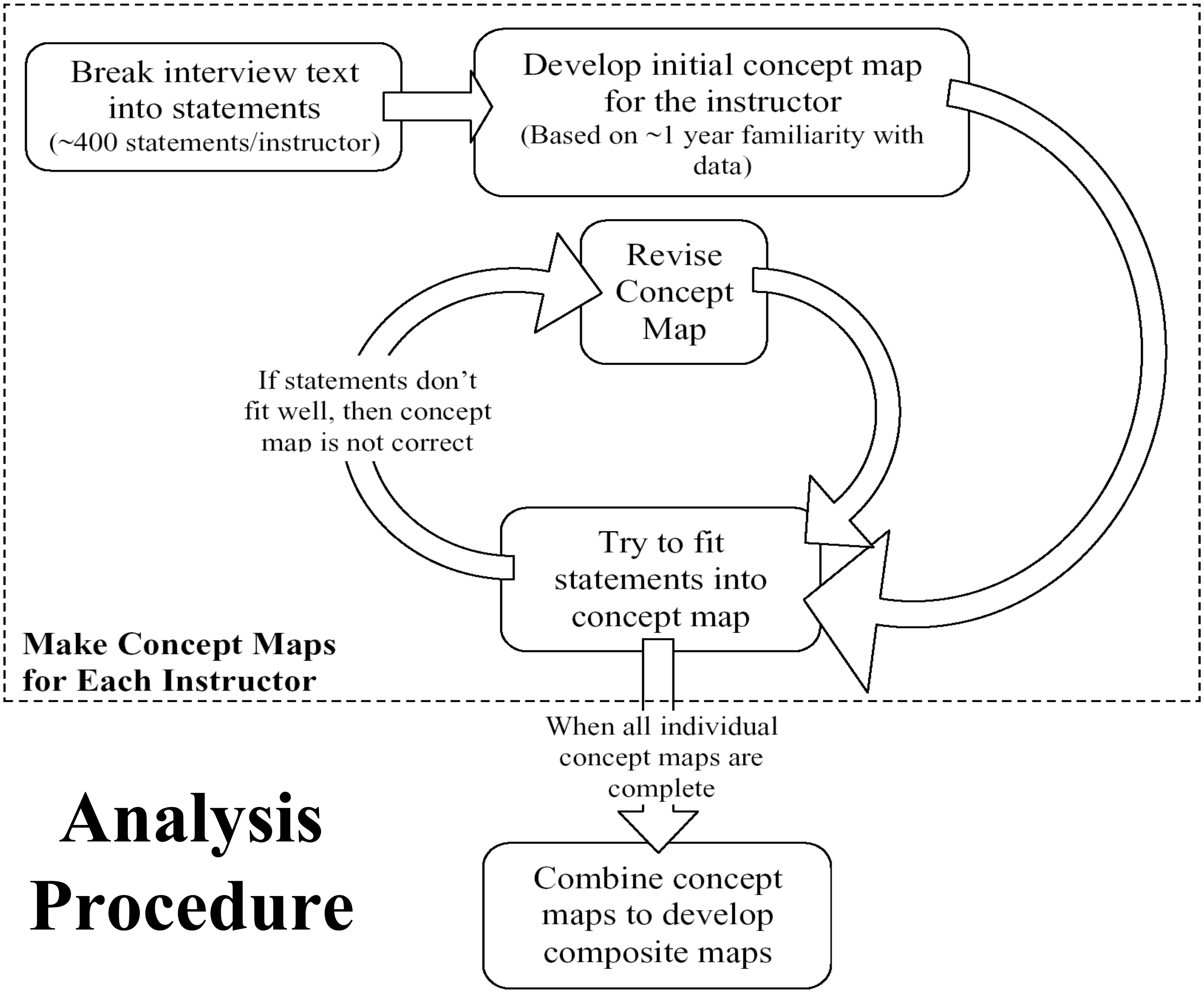
Initial model based on 6 RU instructors

Refine and expand the initial model based on 24 interviews with instructors from different institutions in the state of MN

Determine the distribution of conceptions among instructors using a larger national sample

Sharpen understanding using an international sample

Focused Study – Large Sample



Analysis Procedure

Why Concept Map?

Video- & audiotapes of 6 interviews (> 9 hrs)

Interview transcripts (>180 pages)

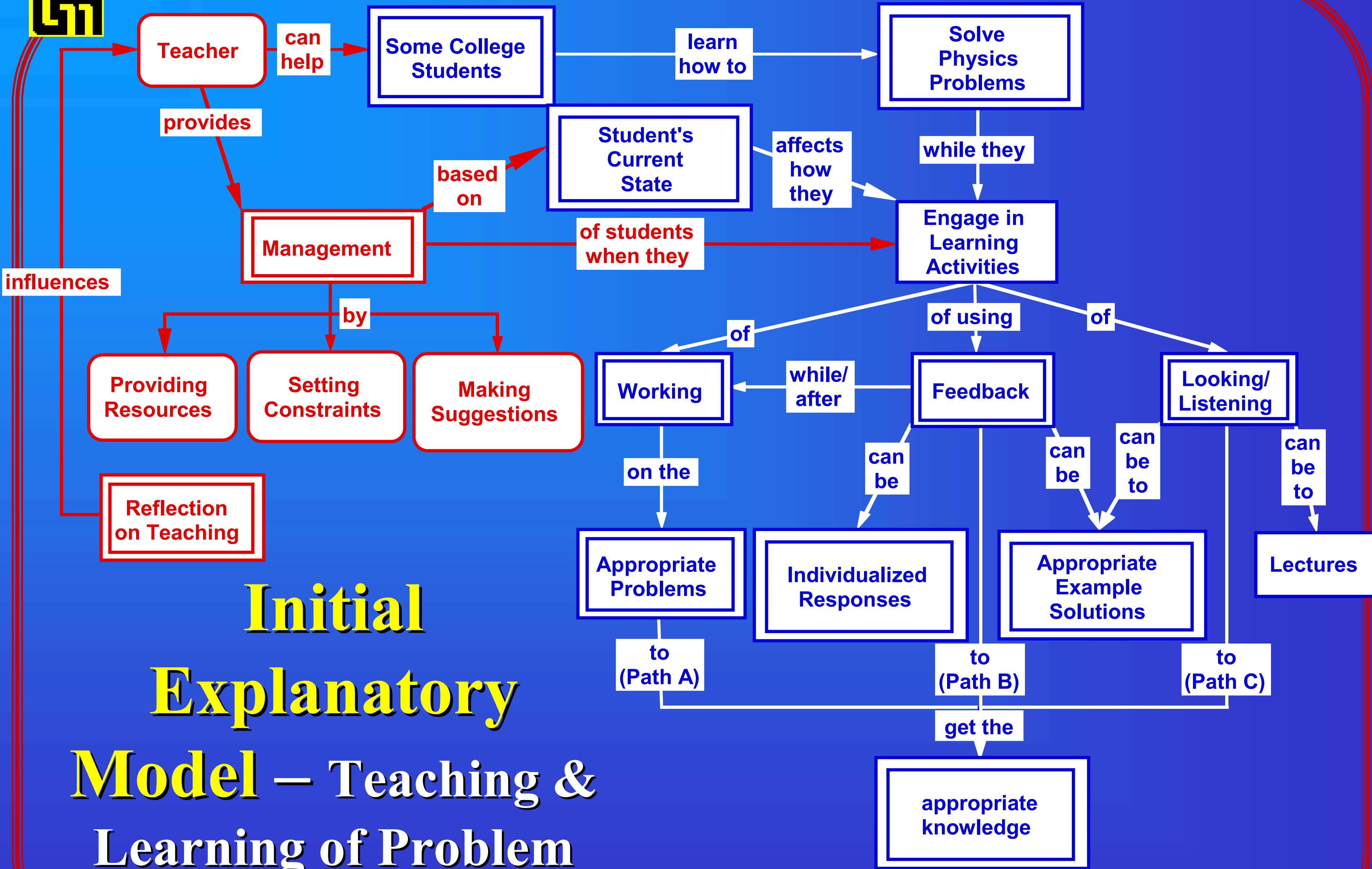
Statements (>2400)

Concept Maps (14 x 6 = 84)

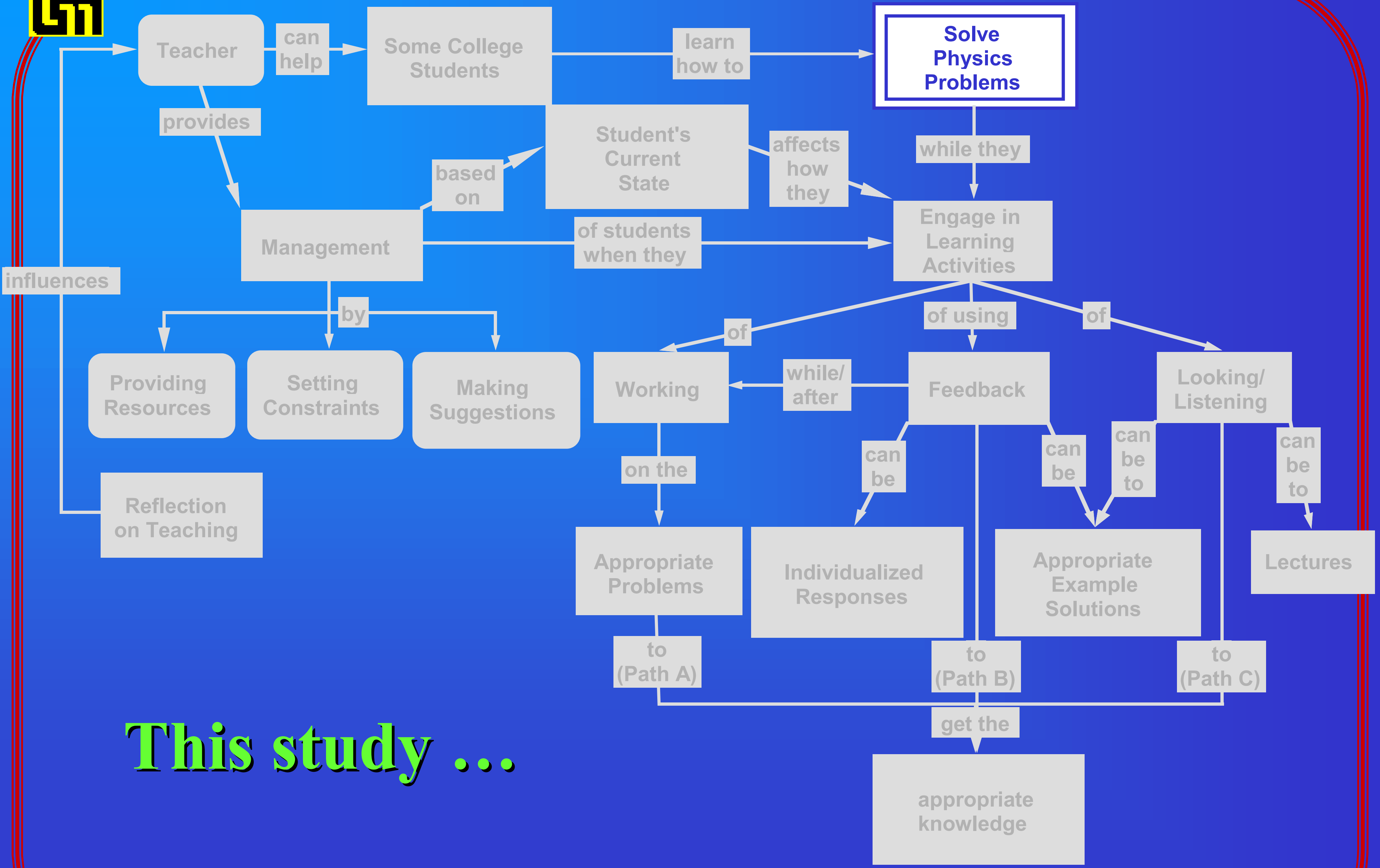
Combined Concept Map (14)

Concept Maps allow for:

- **reduction** of complex data into visual representations
- **explicit connections** to be made between ideas that can then be tested



Initial Explanatory Model – Teaching & Learning of Problem Solving


Teacher
can help
Some College Students
learn how to
Solve Physics Problems
provides
Student's Current State
based on
affects how they
while they
Management
of students when they
Engage in Learning Activities
influences
by
of
of using
of
Providing Resources
Setting Constraints
Making Suggestions
Working
while/ after
Feedback
Looking/ Listening
on the
can be
can be
can be to
can be to
Reflection on Teaching
Appropriate Problems
Individualized Responses
Appropriate Example Solutions
Lectures
to (Path A)
to (Path B)
to (Path C)
get the
appropriate knowledge

This study …

What is Problem Solving?

"Process of Moving Towards a Goal When the Path is Uncertain"

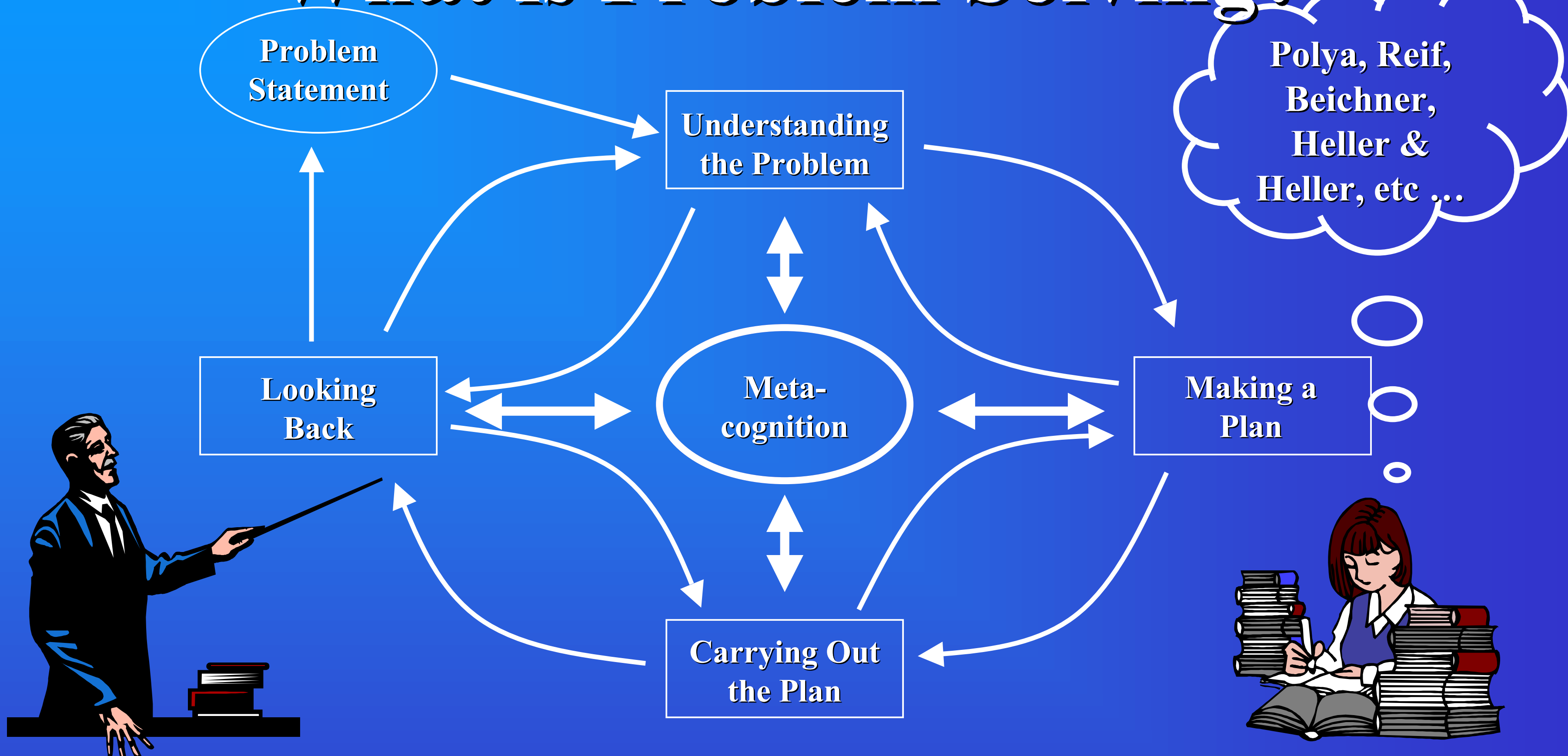
- If you know how to do it, it is not a "problem"
- A problem for a student is not a problem for the faculty

  Exercise vs. Problem

- Problems are solved using tools
  - General Purpose Heuristics
- Problem Solving involves Uncertainty and Mistakes

M. Martinez (1998), *Phi Beta Kappan*, April

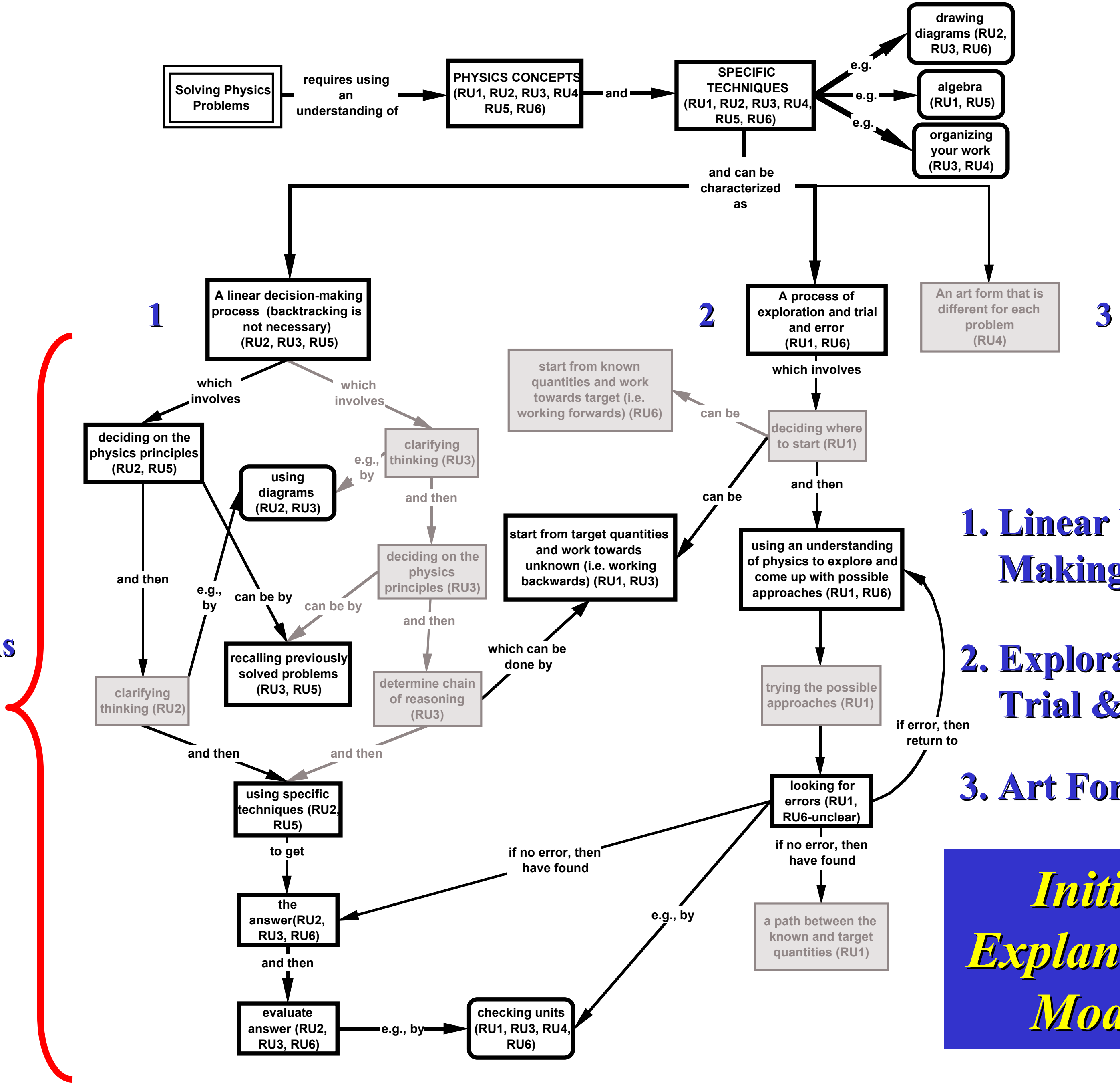
What is Problem Solving?



Limitation: Instructors' conceptions are inferred from what they talk about when describing the problem-solving process during the interview, in the context of introductory calculus-based physics, not about how they actually solve problems or how they actually teach

Fernandez, M.L., Hadaway, N., & Wilson, J.W. (1994). Problem Solving: Managing It All. *Connecting Research to Teaching*, 87:3, 195-199.

3 Conceptions of the Problem Solving Process



1. **Linear Decision Making**
2. **Exploration and Trial & Error**
3. **Art Form**

Initial Explanatory Model

The Problem Solving Process

six research university instructors

Conception 1: A linear decision-making process (backtracking is not necessary)

Step 1: "Know" physics principle(s) to use

Step 2: Clarify thinking (e.g. by using diagrams)

Step 3: Use tools (e.g., algebra, FBD) to get answer

Step 4: Evaluate answer

Conception 2: A process of exploration and trial and error

Step 1: Decide on goal (e.g., target to known)

Step 2: "Explore" the problem and "decide" on possibly useful approaches or principles

Step 3: Try most promising approach

Step 4: Evaluate progress (return to step 2 if necessary)

Conception 3: An art form that is different for each problem

(no process given)

Overview of Program

Exploratory Study – Small Sample

Initial model based on 6 RU instructors

•PERC Proceedings (2001)
•PERC Proceedings (2002)
•Henderson Dissertation (2002)
•Henderson, et. al. (2004), *AJP*

Now

Refine and expand the initial model based on 24 interviews with instructors from different institutions in the state of MN
(Community College, Private College, State University)

Determine the distribution of conceptions among instructors using a larger national sample

Sharpen understanding using an international sample

Focused Study – Large Sample

Research Question

To what extend does the Initial Explanatory Model of instructors' conceptions about the problem-solving process need refinement and expansion?

- **There are consequently three sub-questions**
  - **When the sample of instructors is increased from 6 to 30:**

1. **Do the qualitatively different conceptions of the problem-solving process in the Initial Explanatory Model remain the same?**
2. **Where appropriate, can the lack of detail in the problem-solving process be filled?**
3. **Are the different conceptions of the problem-solving process really qualitatively different?**

Targeted Analysis

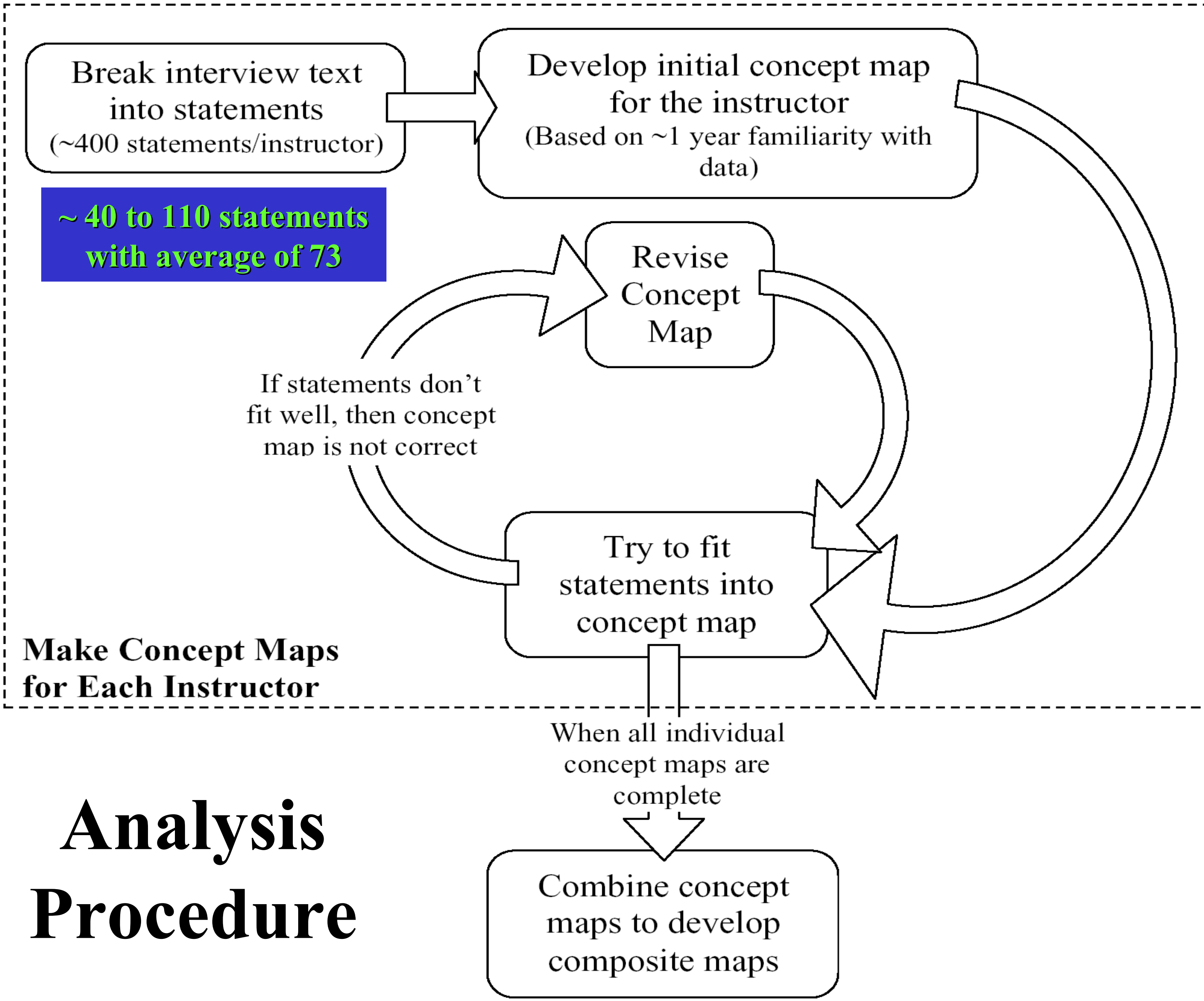
Analyzing interviews is very time consuming

6 interviews → 30 interviews

Target a feature (Problem-Solving Process) of the initial explanatory model and cut down the analysis time

- **Identify** parts of interview where statements about the problem-solving process were found in previous study
- **Analyze** additional interviews
  - Code only statements regarding the problem-solving process
  - Generate problem-solving process concept map
- **Refine Initial Explanatory Model** (randomly selected, non-research university faculty)
- **Develop Refined Explanatory Model**

Analysis Procedure



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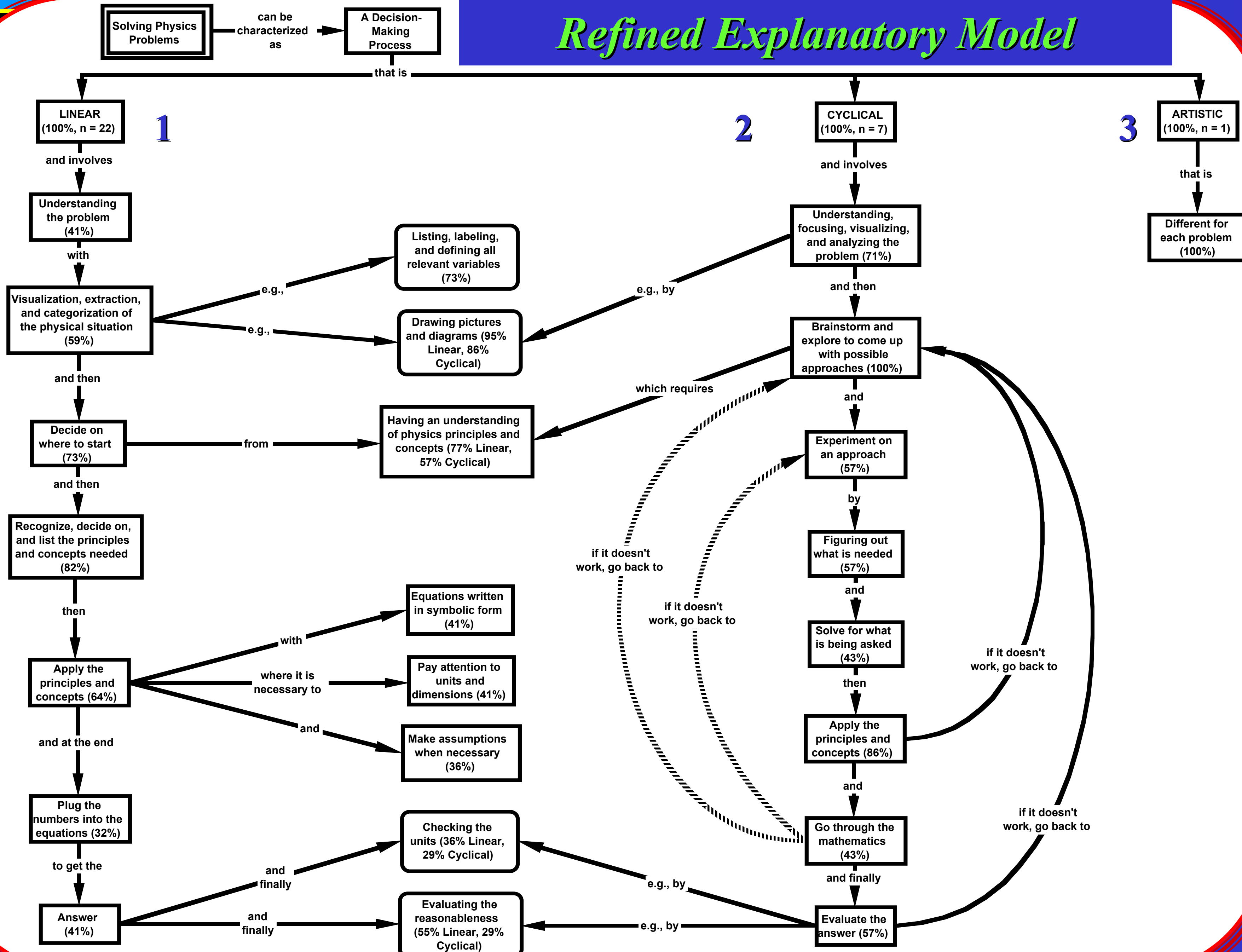
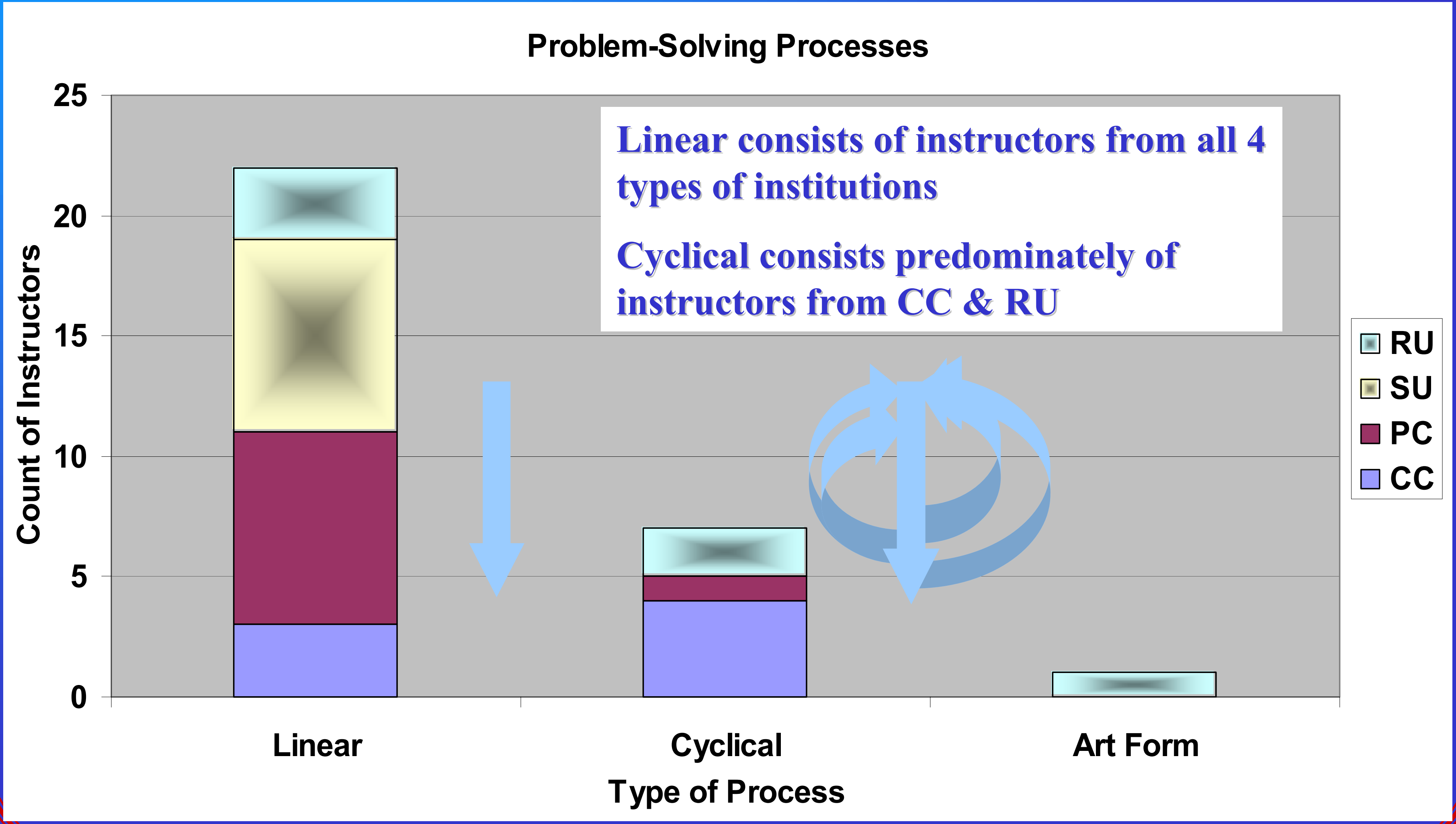
Refined Explanatory Model



Description of Problem Solving Process by Institutional Type – Type of Process



Answer to sub-question 1

Different Conceptions of the Problem-Solving Process	Initial Explanatory Model (Exploratory Study – n = 6)	Refined Explanatory Model (Convergent Study – n = 30)
1	*Linear Decision-Making Process (3)*	*Decision-Making Process that is Linear (22)*
2	*Process of Exploration and Trial and Error (2)*	*Decision-Making Process that is Cyclical (7)*
3	*An Art Form that is different for each problem (1)*	*An Art Form that is different for each problem (1)*

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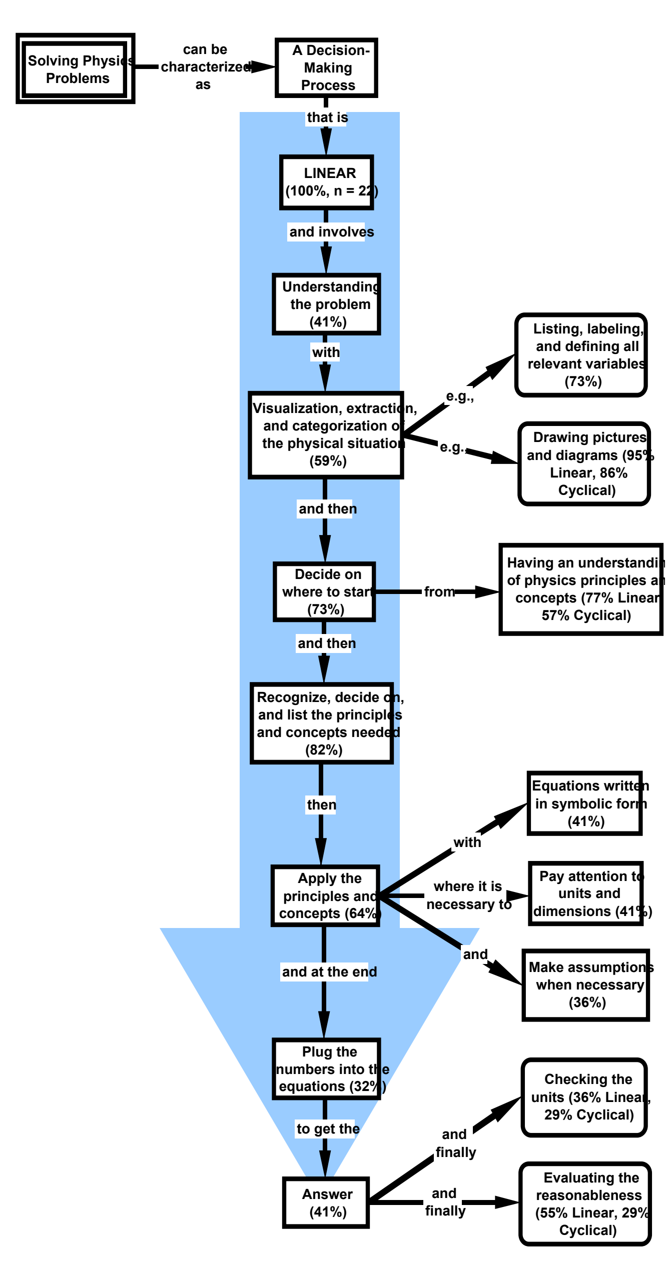
1. Decision-Making Process – Linear (n = 22)



Step 1: "Know" physics principle(s) to use

Step 2: Clarify thinking (e.g. by using diagrams)

Step 3: Use tools (e.g., algebra, FBD) to get answer

Step 4: Evaluate answer

Step 1: Understand the problem

Step 2: Visualize, extract, & categorize the physical situation

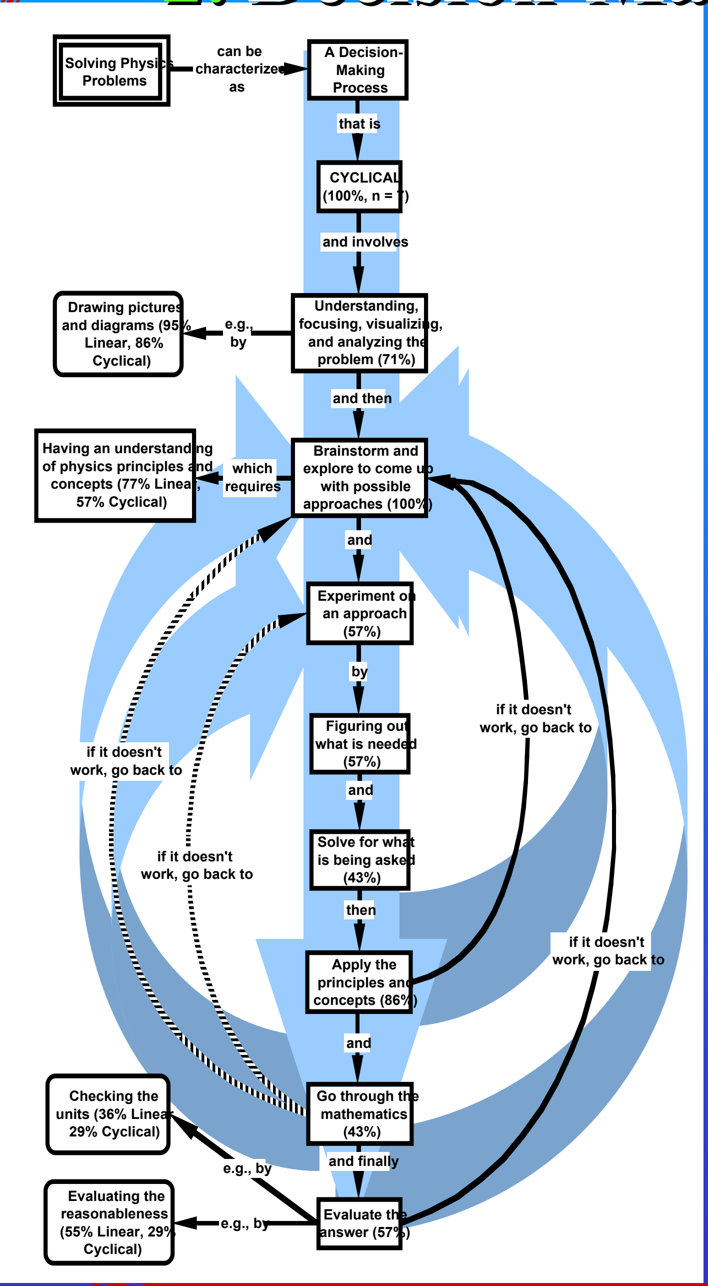
Step 3: "Know" the correct physics principle(s) & figure out an approach based on experience of having solved many problems

Step 4: Apply the principle(s) & make assumptions when necessary

Step 5: Go through the mathematics

Step 6: Evaluate the answer

2. Decision-Making Process - Cyclical (n = 7)



Step 1: Decide on goal (e.g., target to known)

Step 2: "Explore" the problem and "decide" on possibly useful approaches or principles

Step 3: Try most promising approach

Step 4: Evaluate progress (return to step 2 if necessary)

Step 1: Understand, focus, & visualize the problem

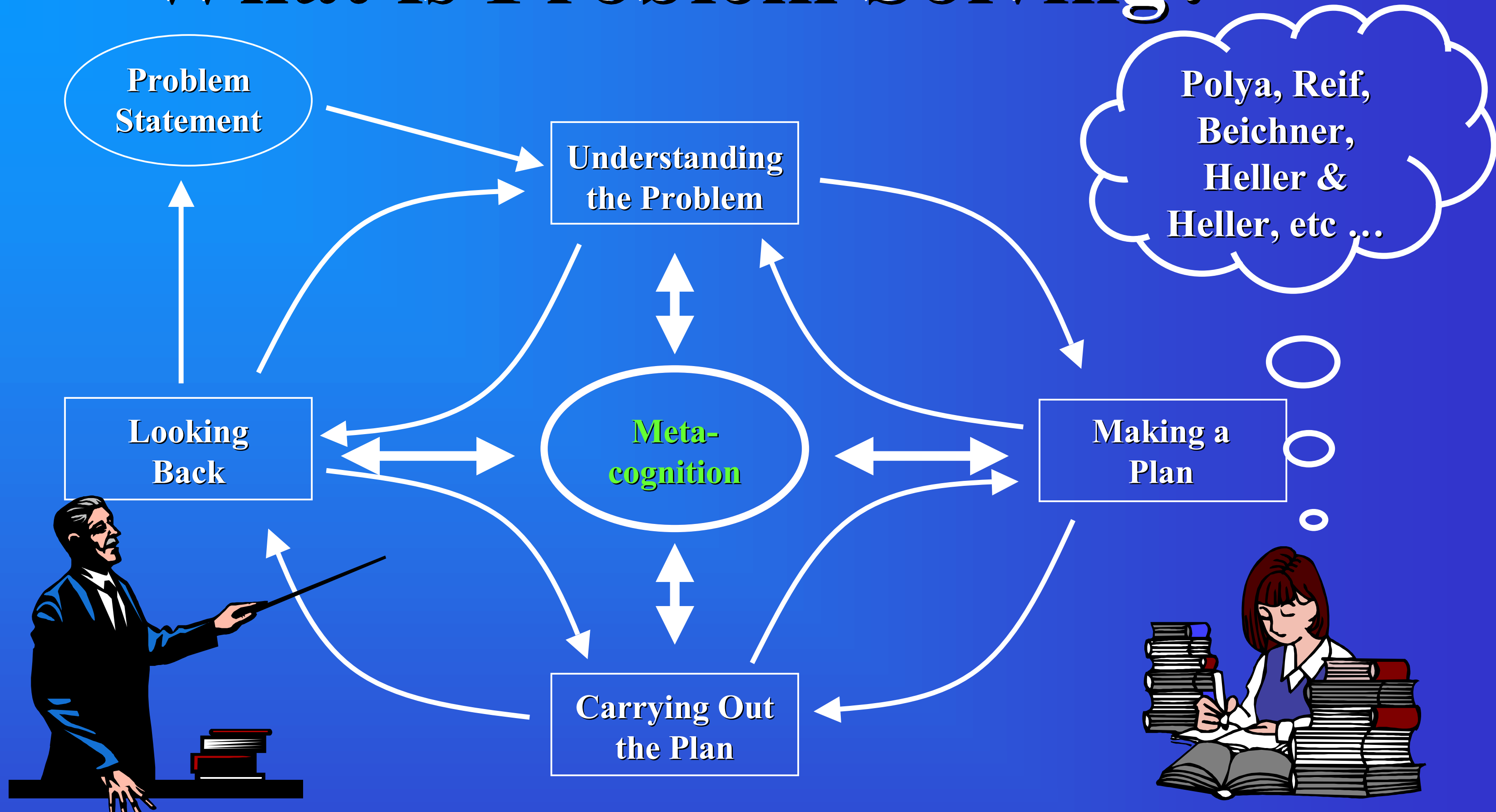
Step 2: "Brainstorm" & "Explore" to come up with possible approaches & principle(s)

Step 3: "Experiment" on an approach by deciding on where to start & apply the principle(s) (go back to Step 2 as necessary)

Step 4: Go through the mathematics (go back to Step 2 or Step 3 as necessary)

Step 5: Evaluate the answer (go back to Step 2 as necessary)

What is Problem Solving?



Limitation: Instructors' conceptions are inferred from what they talk about when describing the problem-solving process during the interview, in the context of introductory calculus-based physics, not about how they actually solve problems or how they actually teach

Fernandez, M.L., Hadaway, N., & Wilson, J.W. (1994). Problem Solving: Managing It All. *Connecting Research to Teaching*, 87:3, 195-199.

What is Metacognition?

- People's Thinking about their own Thinking

Flavell, Freidrichs, & Hoyt, 1970; Bisanz, Vesonder, & Voss, 1978; Cavanaugh & Borkowski, 1979; Kluewe, 1982; Lodico, Ghatala, Levin, Pressley, & Bell, 1983; Schneider, 1985; Schoenfeld, 1987; Paris & Winograd, 1990; Nelson & Dunlosky, 1991; Borkowski & Muthukrishna, 1992

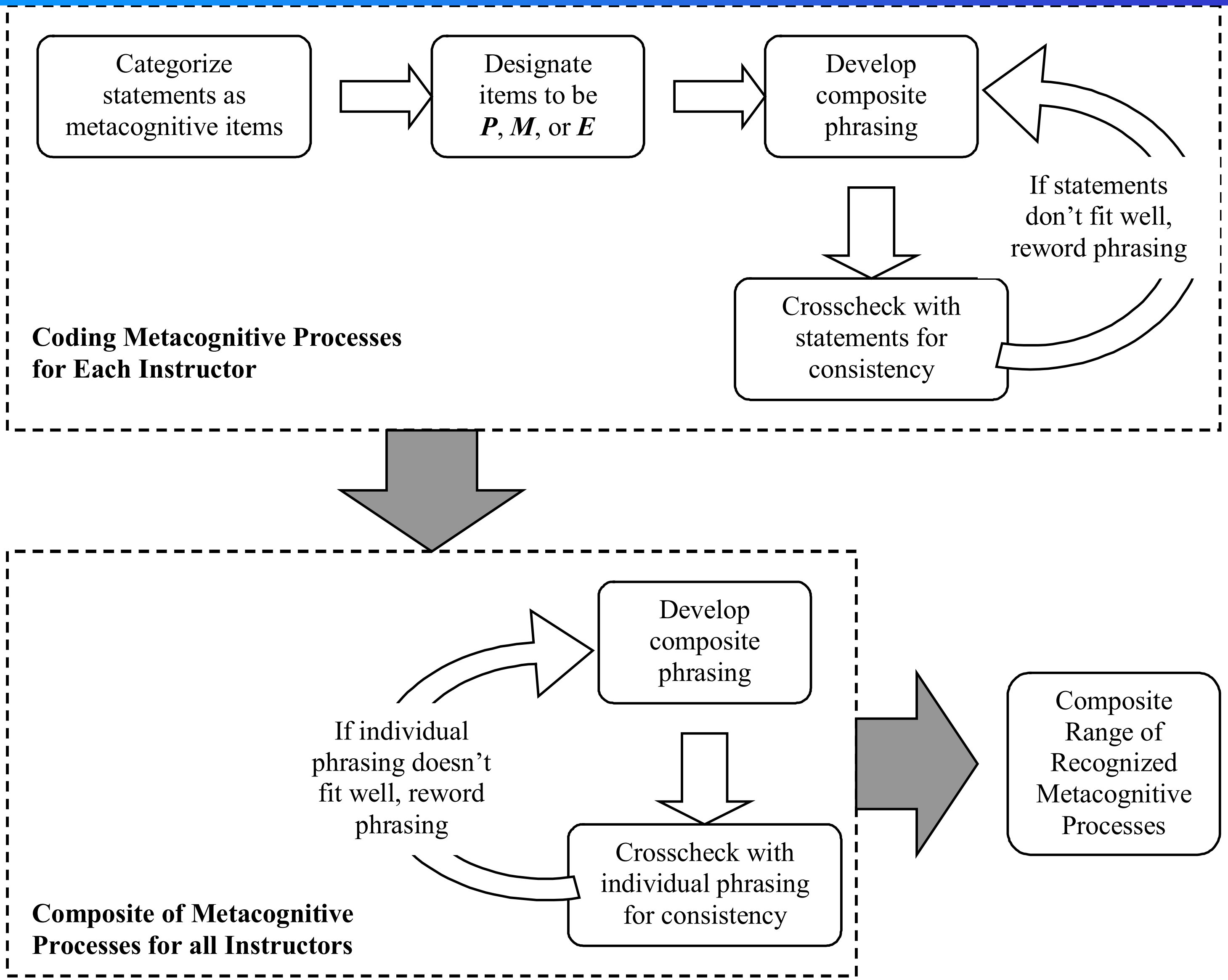
Underlies all higher order thinking, especially problem solving!

Why do we care?

- Research has indicated (Schoenfeld, 1983, 1985a, 1985b, 1987;Lester, Garofalo, & Kroll, 1989)
  - Successful problem solvers spend more time … *planning* the directions that may be taken … *monitor* and *evaluate* their actions and cognitive processes throughout problem-solving episodes than do less successful problem solvers

Let’s see how these instructors view the role of metacognition

Procedure for analysis of metacognition



Metacognition – Bulk

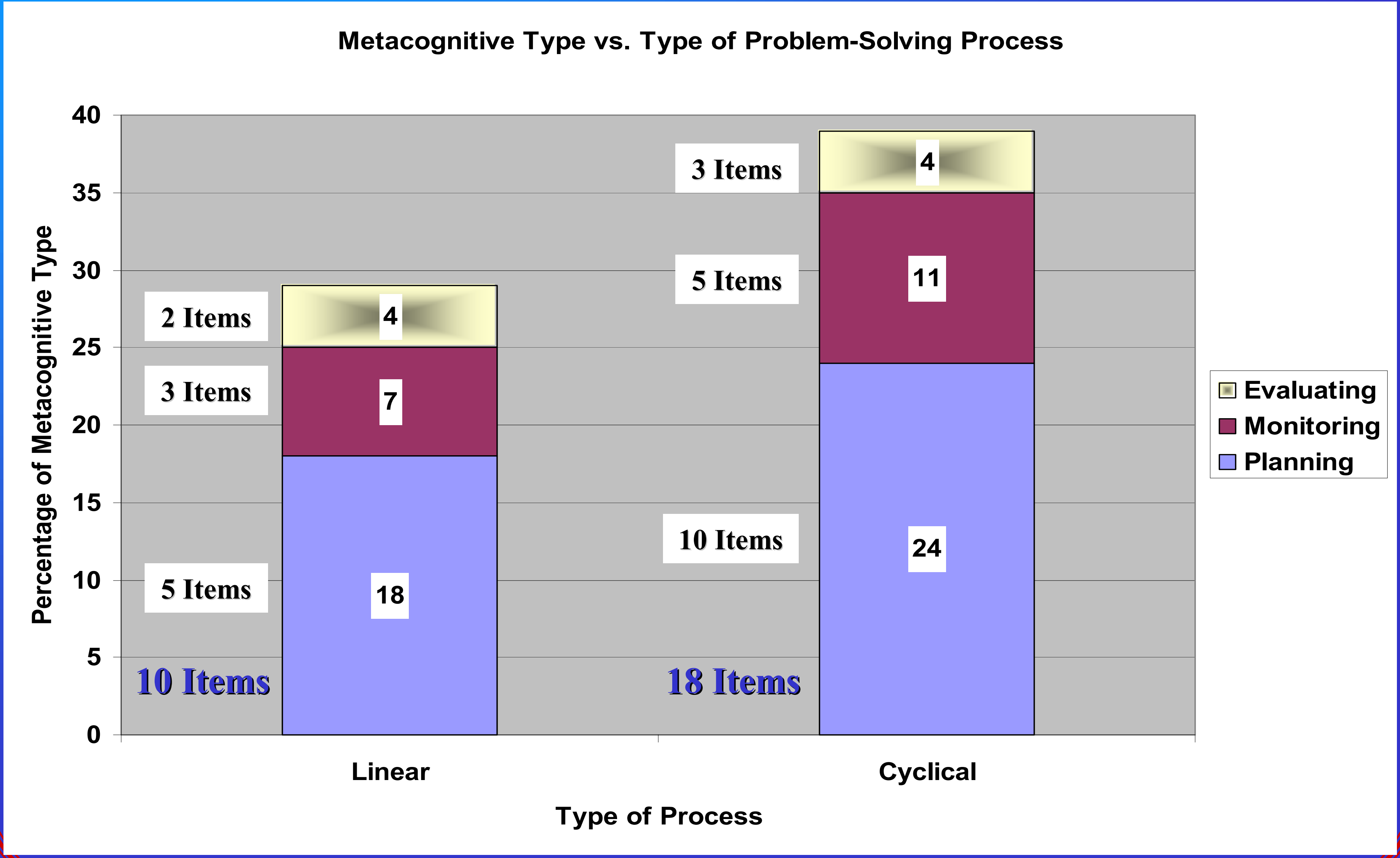
A naïve assumption could be that these instructors would consider *planning*, *monitoring*, and *evaluating* equally in problem solving

Count	Number of Statements				
	Problem Solving	Metacognition	Planning	Monitoring	Evaluating
Min	14	7	3	0	0
Max	116	53	31	21	8
Average	65	20	12	6	2
Total	1948	606	*360*	*172*	*74*

$H_0: n_p = n_m = n_e$ → $\chi^2 = 209.15$, $p < 0.000$

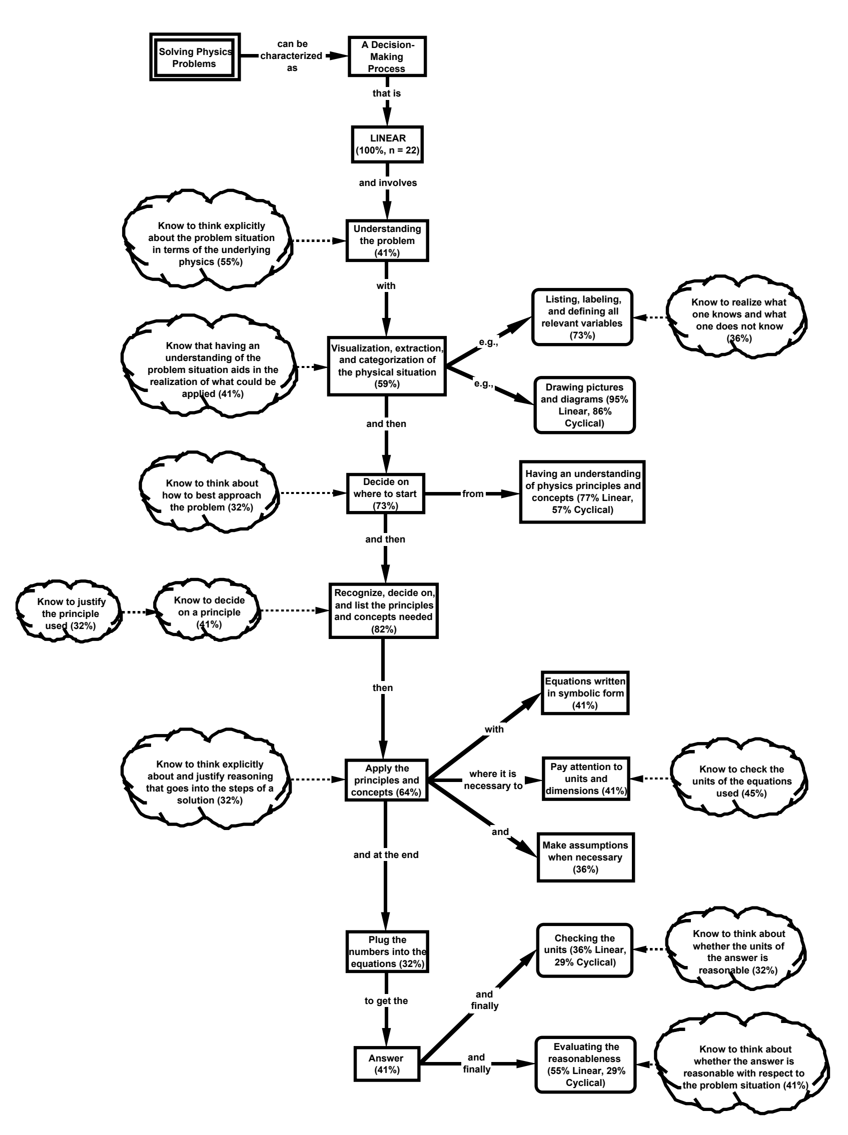
These instructors, as a whole, did not talk about the three types of metacognition equally when describing the problem-solving process

Metacognition – Different Types

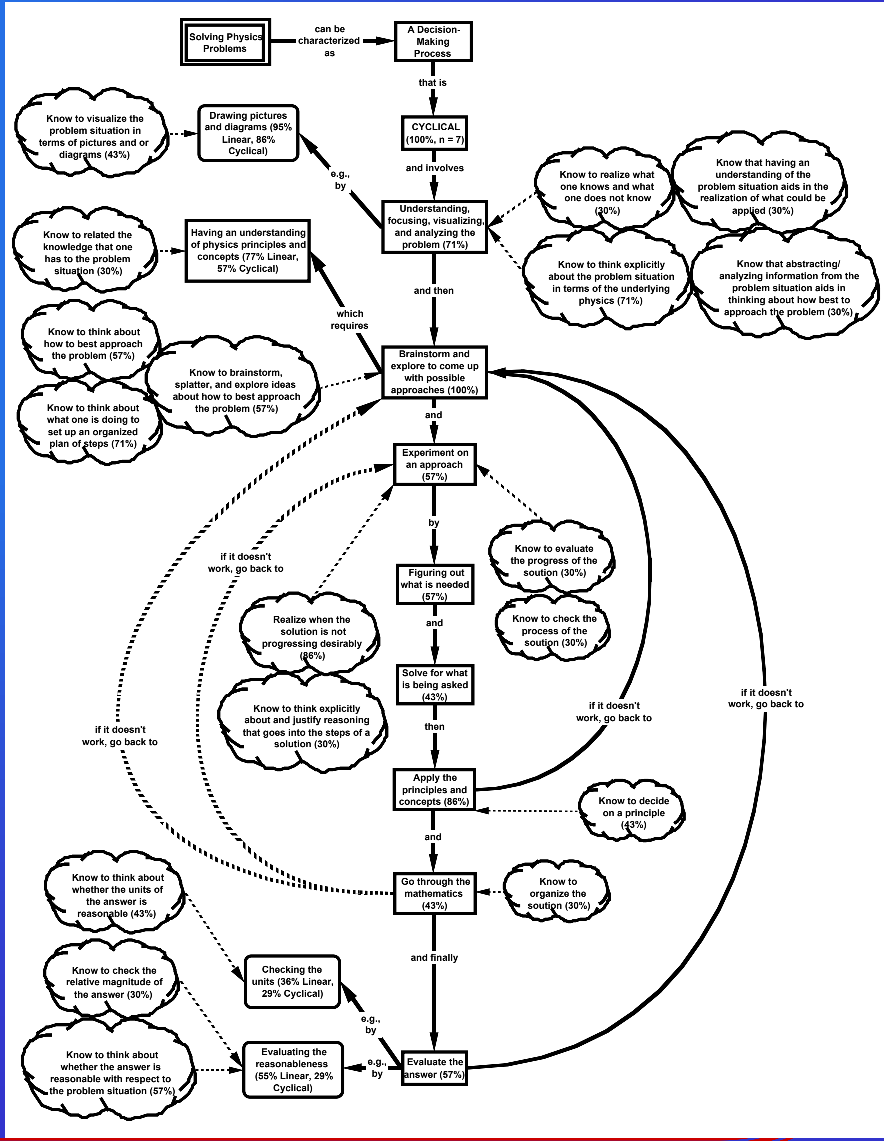


Metacognition – Different Conceptions

Linear

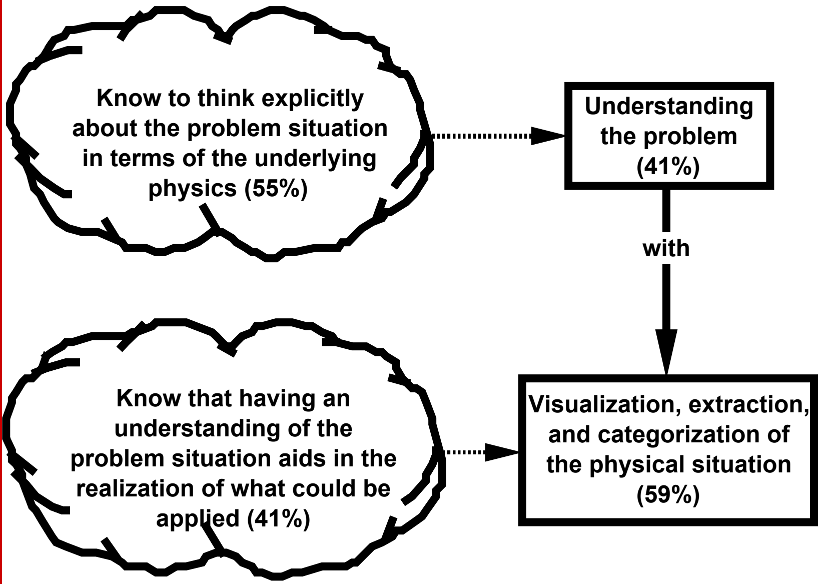


Cyclical

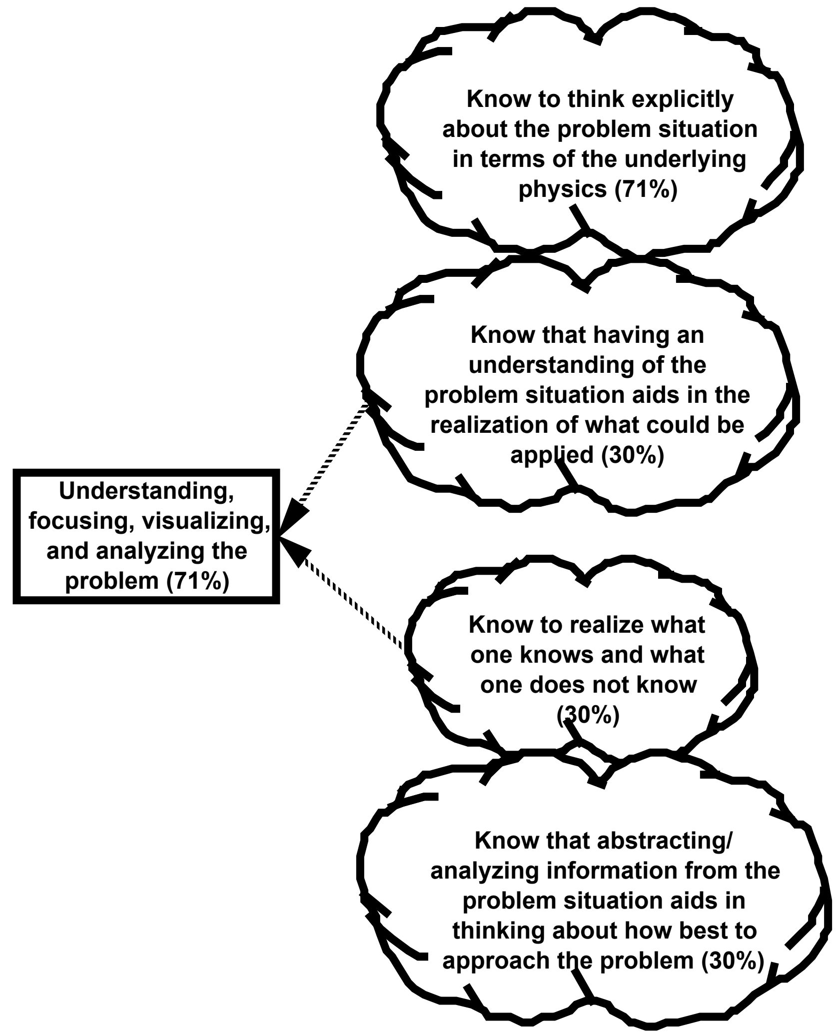


Metacognition – Example Comparison

Linear

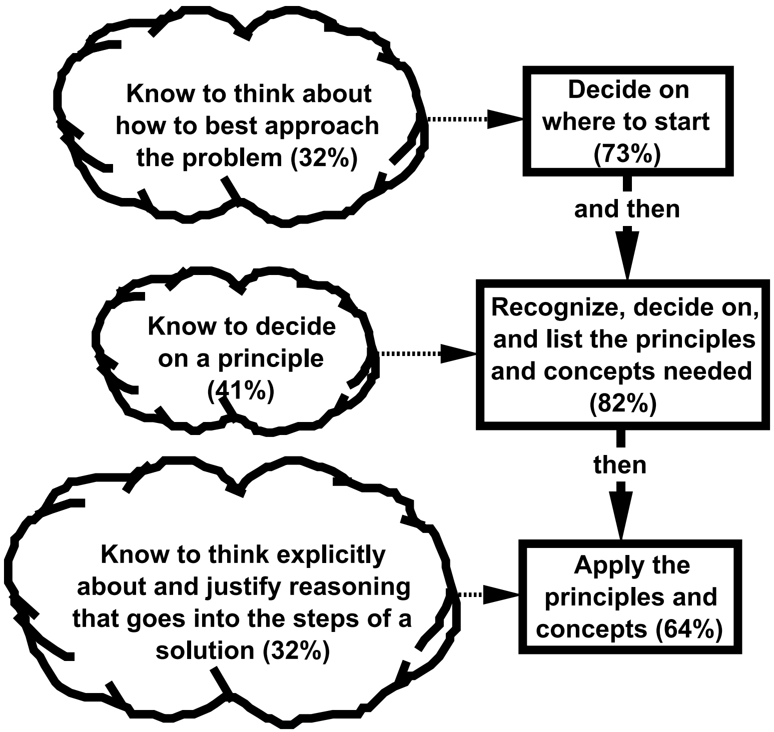


Cyclical

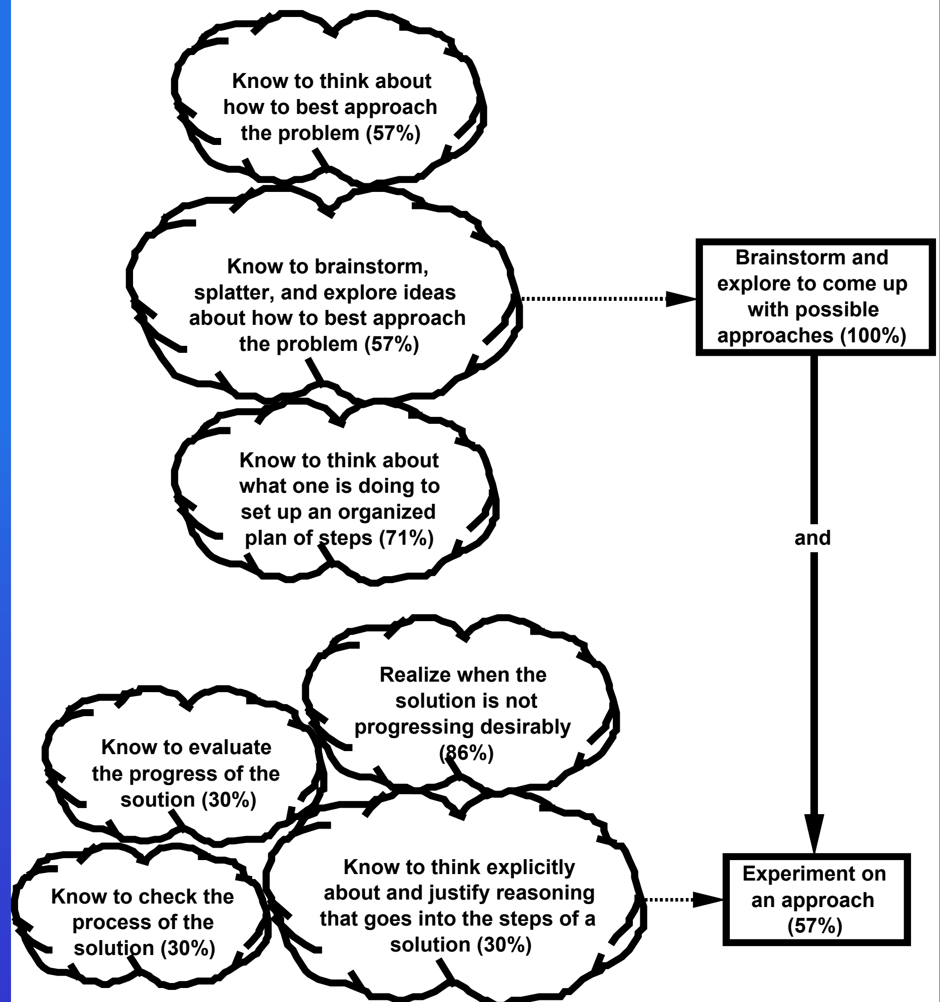


Metacognition – Example Comparison

Linear



Cyclical



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Internal Consistency

- To answer that question, I looked at the details of the individual concept maps within each of the 2 different conceptions

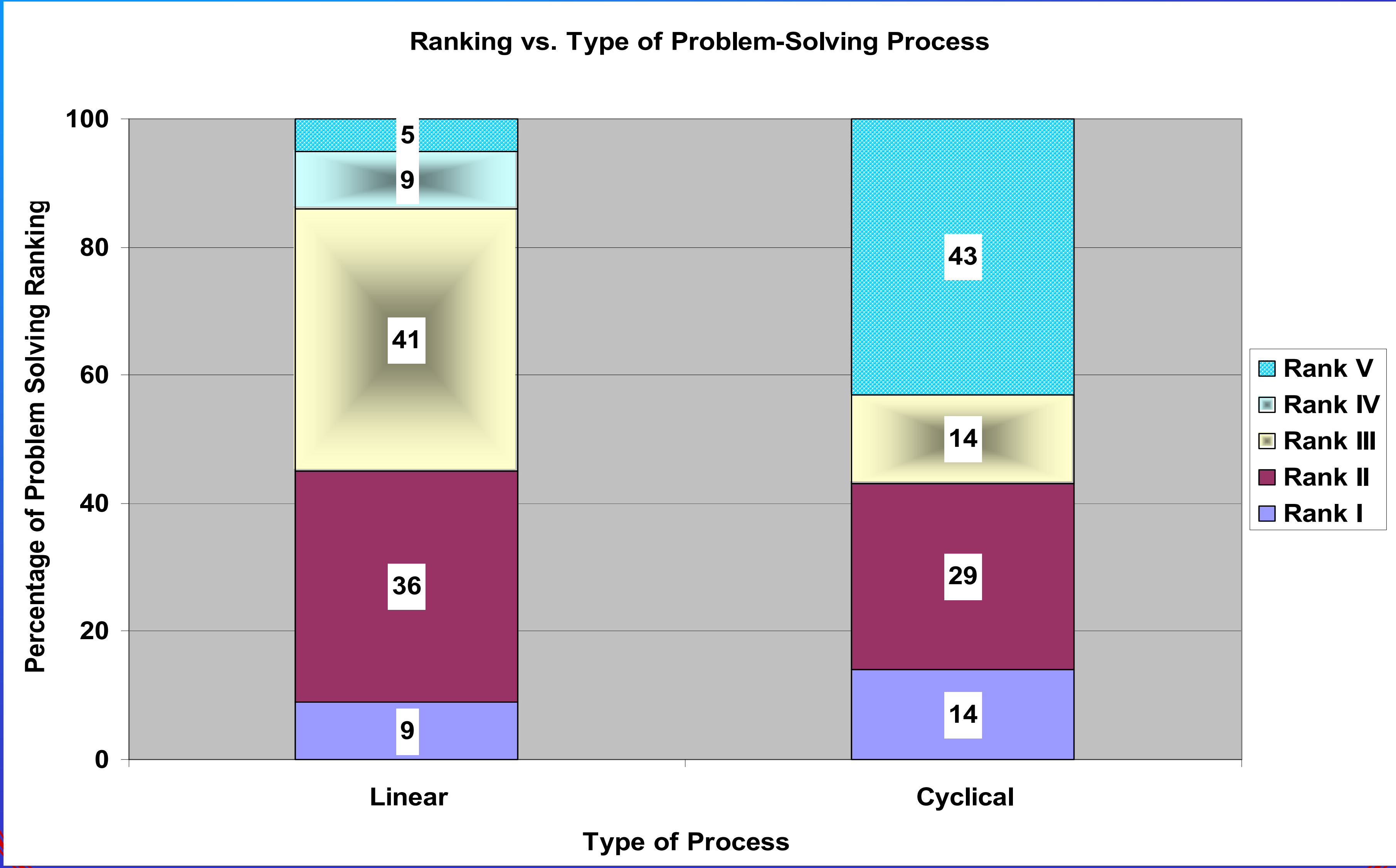
  a) Ranking of Concept Map

  I to *V*, designating levels of detail with respect to “requirement”, “rationale”, & “secondary clarification”

Categories	*I*	*II*	*III*	*IV*	*V*
Criteria **Components of PS Process:** **Understand the Problem; Make Plan; Carry out Plan; Looking Back** ***(Do not code in lesser category if only "Looking Back" is missing)*** **Requirement:** Information necessary to help execution of main item **Reason:** rationale that describes how/why item helps facilitate moving solution forward **Secondary Clarification:** information that clarifies what the main item entails **Interconnections:** connecting links (i.e., logic loops) between different components & items within the PS Process	Consists of a *bare-bones* skeleton of components ***with*** *No* **Requirements** listed, *and* *No* **Reasons** listed, *and* *No* **Secondary Clarifications** listed, *and* *No* **Interconnections** apparent in concept map	Consists of a complete skeleton of components (with the exception of *"Looking Back"*), *and* Contains at least 1 **Requirement**, *and* Contains at least 1 **Reason**, *and* Contains at least 2 **Secondary Clarification**, *and* ***2 out of 3 from above plus*** *Sum* of Req, Rea, & 2'nd Cla $0 \leq 4$, and *0 or 1* **Interconnection** apparent in concept map	Consists of a complete skeleton of components (with the exception of *"Looking Back"*), *and* Contains at least 2 **Requirement**, *and* Contains at least 2 **Reason**, *and* Contains at least 2 **Secondary Clarification**, *and* ***2 out of 3 from above plus*** *Sum* of Req, Rea, & 2'nd Cla $4 \leq 6$, and *1 or 2* **Interconnections** apparent in concept map If *SUM* is large enough, but # of **Interconnection** is too low (i.e., "0"), drop down to *Category II*	Consists of a complete skeleton of components (with the exception of *"Looking Back"*), *and* Contain at least 3 **Requirement**, *and* Contain at least 3 **Reason**, *and* Contains at least 3 **Secondary Clarification**, *and* ***2 out of 3 from above plus*** *Sum* of Req, Rea, & 2'nd Cla $6 \leq 9$, and *2 or 3* **Interconnections** apparent in concept map If *SUM* is large enough, but # of **Interconnection** is too low (i.e., "1 or less"), drop down to *Category III*	Consists of a complete skeleton of components (with the exception of *"Looking Back"*), *and* Contains more than 3 **Requirement**, *and* Contains more than 3 **Reason**, *and* Contains more than 3 **Secondary Clarification**, *and* ***2 out of 3 from above plus*** *Sum* of Req, Rea, & 2'nd Cla > *9*, and *3 and up* **Interconnections** apparent in concept map If *SUM* is large enough, but # of **Interconnection** is too low (i.e., "2 or less"), drop down to *Category IV*

1. *If Sum is on the border of 2 Categories, use the number of interactions to decide on the appropriate Category*
2. *If multiply-linked items on a map can be thought of as a single chain of thought, it should only be counted once as a Requirement, Reason, or Secondary Clarification*
3. *Interconnections are links between different items of the problem-solving process that are logically related*

Internal Consistency



External Consistency

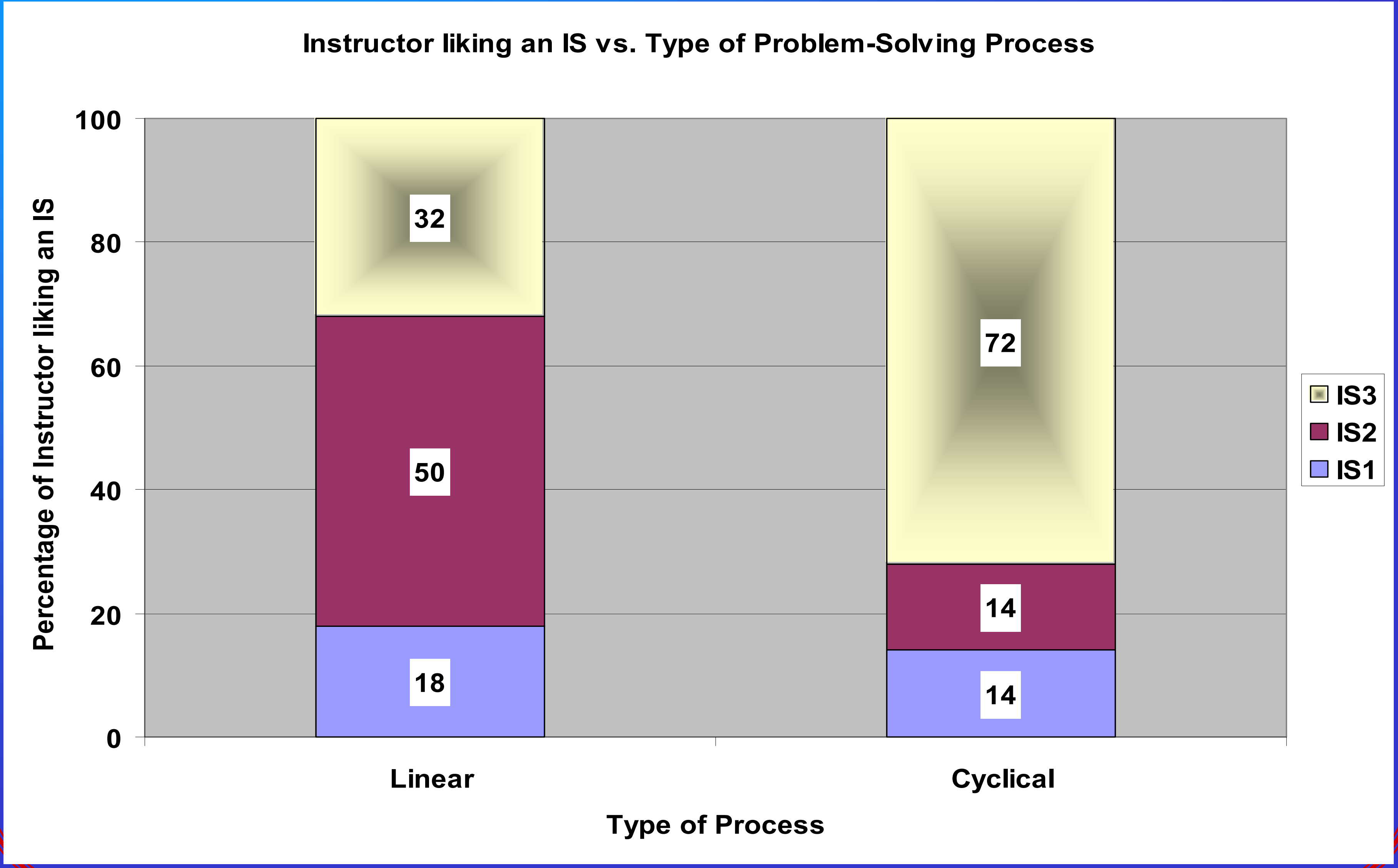
- To answer that question, I also looked at other sources of data
  - b) Instructor liking an Example IS

    IS1: Bare-Bone

    IS2: Step-by-Step with Rationale

    IS3: Planning before Execution

External Consistency



External Consistency

- To answer that question, I also looked at other sources of data

  b) Instructor liking an Example IS

  c) Solve problems using general quantitative PS skills within the context of physics

Very Important

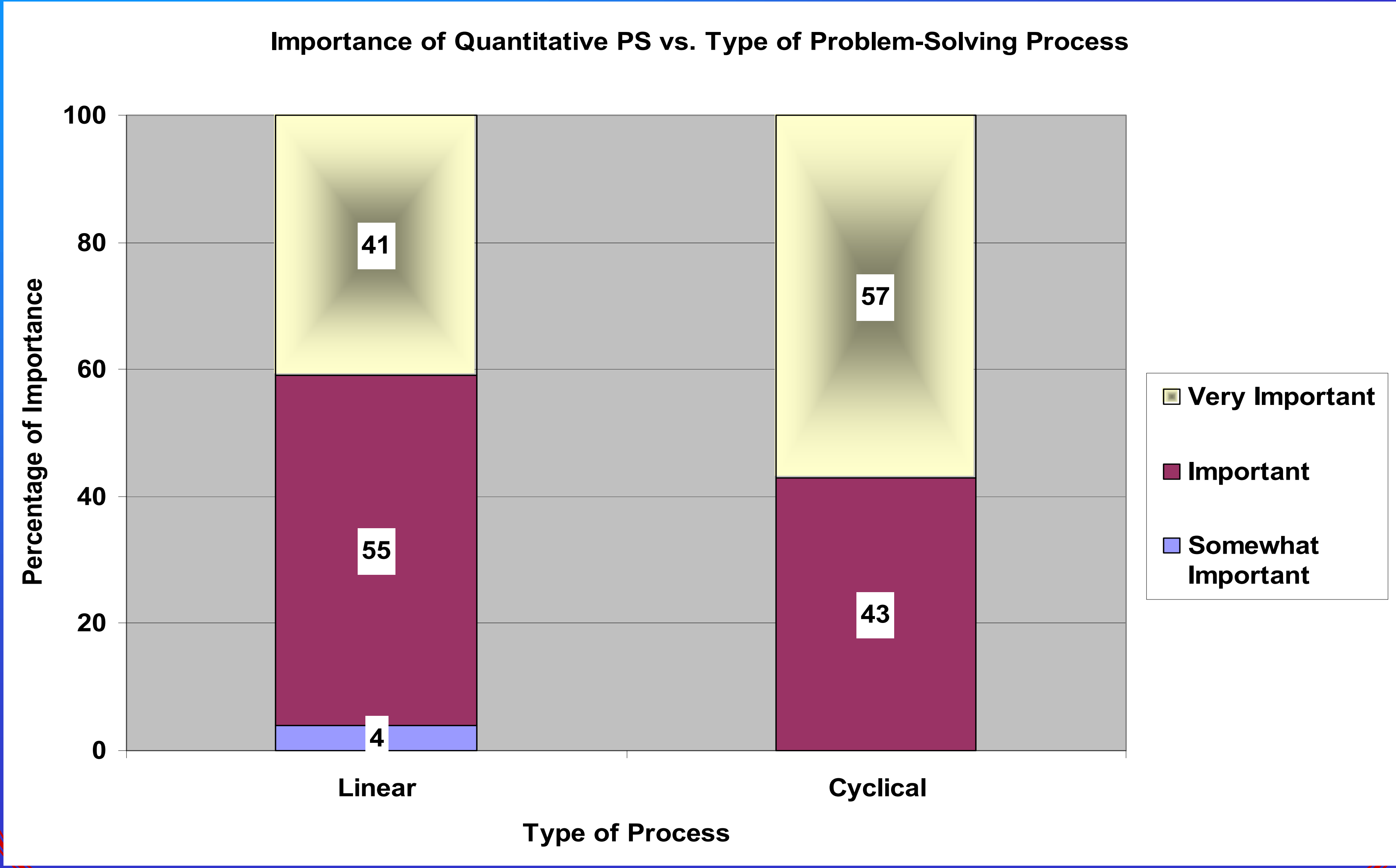
Important

Somewhat Important

Slightly Important

Unimportant

External Consistency



External Consistency

- To answer that question, I also looked at other sources of data
  - b) Instructor liking an Example IS
  - c) Importance of Quantitative PS
  - d) Solve problems using general qualitative PS skills within the context of physics

Very Important

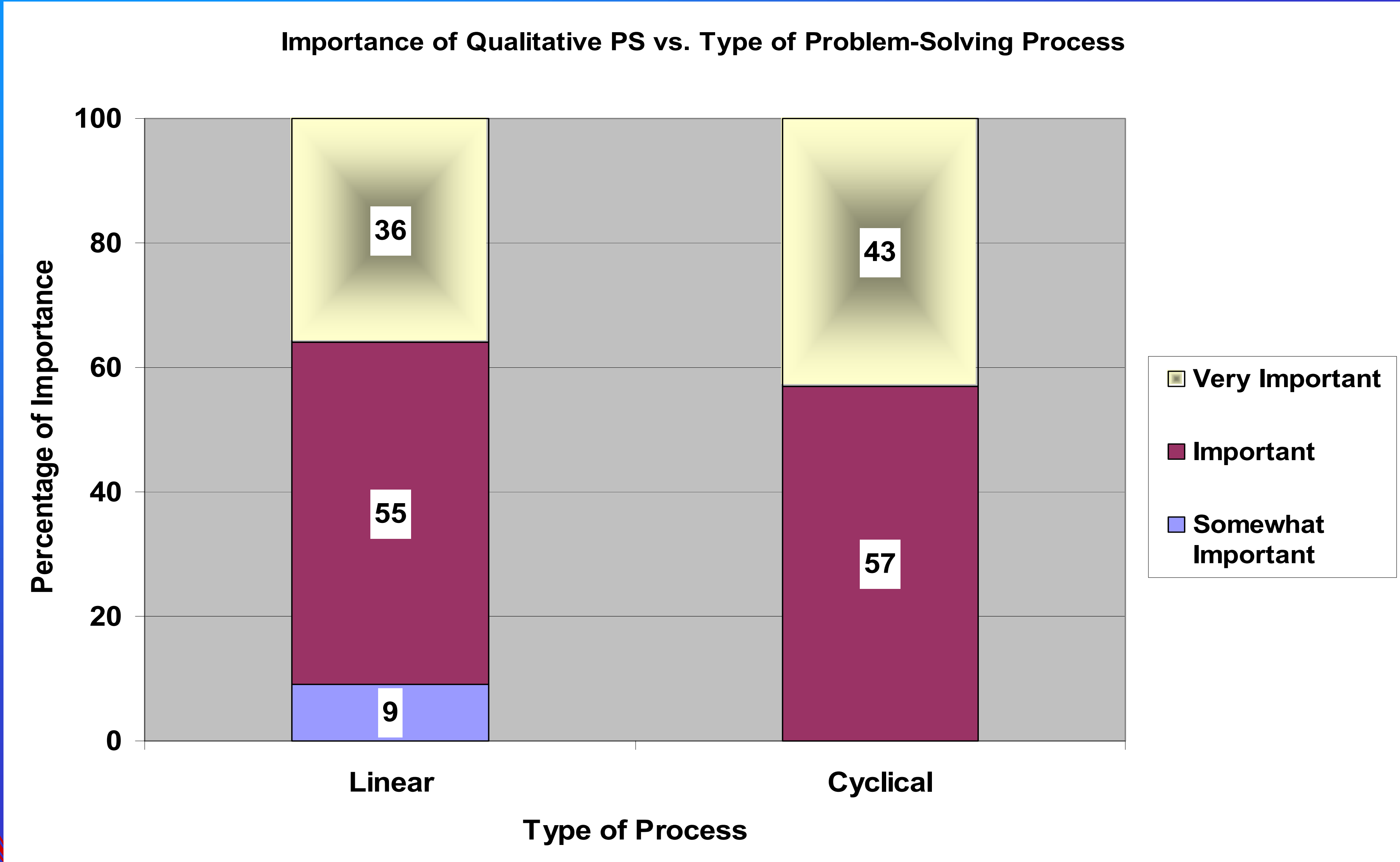
Important

Somewhat Important

Slightly Important

Unimportant

External Consistency



Consistency Checks – Wrap Up

Looking at the details within the 2 different conceptions, and comparing across various other sources of data …

Internal

a. Ranking of Concept Map

External

b. Liking an IS

c. Importance of Quantitative PS

d. Importance of Qualitative PS

All showed qualitative differences and similar trends!

Summary

Two qualitatively different conceptions of the problem-solving process: Linear and Cyclical

Qualitative Differences	*Linear*	*Cyclical*
Decision on Approach	*Know*	*Brainstorm, Explore, and Experiment*
Backtracking	*Not Necessary*	*Necessary*
Uncertainties and Mistakes	*Not part of problem solving*	*Inherent part of problem solving*
Metacognition	*Less Involved*	*More Extensive*

Implications – *Theoretical*

1. The initial explanatory model can serve as a productive framework from which to study instructor conceptions in more detail

2. Increased observational reliability (*analysis over smaller segments, articulation of more explicit descriptions of model elements, refinements of model elements, and triangulation of observational support*)
   - provided a means for generalizing over samples in the same population
   - strengthened the refined explanatory model as a more viable model

Implications – *Methodological*

1. Identification of relevant segments of the interview allowed for a more targeted analysis procedure that is the nature of more convergent studies

2. The analysis method made the model elements and interconnections explicit
   - proved to be useful when critiquing and refining
   - provided a transparent way to include reference

3. Specific targeting of problem solving effective in uncovering other implicit conceptions that underlie the process

Implications – *Practical*

Research has shown that problem-solving frameworks that embody metacognitive processes can be effective tools in the instruction of problem solving

It is unclear, however, if physics instructors, as experts in the field, can adequately unpack the internalized knowledge on their own so as to make the instruction on problem solving and metacognition explicit and coherent

1. **Instructors expressed conceptions similar to the problem-solving frameworks in literature (with different words and number of steps)**
   - **Frameworks and instructional structures must be flexible so instructors have the freedom to refine as they see fit**
   - **Frameworks and instructional structures must be robust so that the refinements are not detrimental**

Implications – *Practical*

Research has shown that problem-solving frameworks that embody metacognitive processes can be effective tools in the instruction of problem solving

It is unclear, however, if physics instructors, as experts in the field, can adequately unpack the internalized knowledge on their own so as to make the instruction on problem solving and metacognition explicit and coherent

2. **Instructors expressed limited conceptions about certain metacognitive processes (not as much *monitoring* and *evaluating* as *planning*)**
   - **Frameworks and instructional structures must explicitly address all metacognition, and provide language with which to frame such metacognition during instruction**
   - **Frameworks and instructional structures must provide opportunities to experience the benefits**

Next Steps …

- Close-ended survey/questionnaire for determining the distribution of physics instructors' conceptions in national sample
  - Conceptions on process
  - Conceptions on decision making
  - Main units of process
  - Detail of process
  - Role of Metacognition
  - Types of Metacognition
  - etc …

Thanks Everybody!

Please visit our website for more information:

http://groups.physics.umn.edu/physed/

Or send Email to:

vkuo@physics.umn.edu