CAPACITY BUILDING OF KEY RESOURCE PERSONS USING INSERVICE TEACHER PROFESSIONAL DEVELOPMENT PACKAGE IN SCIENCE AND MATHEMATICS FOR SOUTHERN STATES AND UNION TERRITORIES

REPORT

12.03.2014 to 14.03.2014

Coordinator

B S P RAJU

Introduction

Under RMSA, NCERT has developed professional development packages in Science, Mathematics and on generic concerns for the secondary stage teachers. It is proposed and approved for the year 2013-14, PAB (RMSA) for sharing of these packages with all the states/UT's across the country by conducting three day training programmes. As a part of this, RIE Mysore has conducted the 3-day training programme to train the Key Resource persons of the state's Andhrapradesh, Kerala, Karnataka, Tamilnadu, Puducherry and Union Territories Lakshadweep and Andaman and Nicobar Islands, covering the southern parts of India from 12.03.2014 to 14.03.2014.

This training programme is being conducted mainly to build the capacity of the key resource persons selected from the states of Andhrapradesh, Kerala, Karnataka, Tamilnadu, Puducherry and Union Territories Lakshadweep and Andaman and Nicobar islands by the SPD's of the respective states/union territories with Science, Mathematics and general education backgrounds. These key resource persons will be used by the respective states/union territories in organizing the training to the teachers in the secondary and tertiary level training programmes.

Modalities of the programme

The programme is being organized in two batches one for Science and another for Mathematics with some common sessions Continuous Professional development, Inclusive education and understanding the adolescent learner.

The following topics are discussed in

Mathematics

1. Teaching of Algebra
2. Teaching of Geometry
3. Teaching of Statistics
4. Teaching of Number System
5. Teaching of Mensuration

Science

1) Photosynthesis
2) Mole concepts Acids, Bases & Salts
3) Periodic table of elements
4) Electricity & Magnetism
5) Heredity & Evolution
6) Carbon and its compounds
7) Light and sound
8) Diversity in living organisms

Generic issues

1) Continuous Professional Development
2) Inclusive Education
3) Understanding the adolescent learner

Almost all the topics in the packages were discussed.

Details of all the modules were discussed with the participants. Some of the modules have a very few activities. For example the module on photosynthesis has ~~three~~ FOUR activities and all these activities are performed by participants.

During the sessions some of the participants expressed the view that the modules are comprehensive in its scope. The activities were common and simple. They also felt that many of the methodologies applied in teaching the concepts/generalization (for example in Mathematics package) that described in the training package are already known to them.

The participants sought several clarifications in some of the aspects like photochemical reactions of photosynthesis and asked for a review of the topics. This was done to the satisfaction of the participants and they felt happier that many of the doubts were clarified. In some of the sessions last half an hour was spent on how modules can be prepared on other topics in the text book. A lesson plan in Mathematics was also discussed. The teacher must be trained to prepare modules for themselves rather than by depending on the modules written and supplied by outside agencies. The importance of modules for better concept understanding was highlighted during discussions.

Only five participants have attended the programme. Out of which one participant left to his home town after attending two days owing to his ill health.

Topic: Heredity and Evolution (Class X Science)

Date: March 14, 2014 (I Session – 9.30 – 11.00 AM)

By Dr. Mirza Imteyaz Baig, Assistant Professor in Zoology (Contractual), RIE, Mysore

ORGANIC EVOLUTION:

Evolution deals with changes undergone by living things, plants and animals over a long period of time. Plants and animals now living are the modified descendants of somewhat different plants and animals that lived in times past. These ancestors, in their turn, thought of as being the descendants of predecessors that differed from them and so on, step by step, back to a beginning shrouded in mystery. Each animal alive today is the product of long evolutionary history.

Darwin's book, ***"The Origin of Species"***, published in 1859, was the first widely read book on evolution published in English. This classic book focuses on two main objectives: (1) evolution is indeed a fact (2) to present evidence in support of theory of Natural selection.

What makes us to think that the living world of today is not the same as living world as had existed?

The direct evidence on the question just raised comes from the "record of the rocks" from the remains of animals that formerly lived but are now known to us only as fossils. Geologic record demonstrates that hosts of animals not present in the modern world formerly lived. What became of them, and what was their relationship to modern animals?

FOSSILS: The geologic record, or "record of the rocks", is written in the language of fossils. In most frequently encountered fossils the harder parts of the animal's body-bones and teeth in the case of vertebrates, shells of molluscs are the remains of prehistoric animal.

Activity1: The photographs of fossils and different organs were provided to them for arrangement.

They arranged the photographs and pasted on a drawing sheet. At the end each member was asked as to how they had arranged these photographs of fossils and different organs. Based on their response, an elaborate discussion was held to make them understand how exactly fossils support the idea of organic evolution.

Conclusion: They were able to arrange fossils based on their previous knowledge of vertebrates and invertebrates and concluded that one group of organisms might have given rise to higher groups (based on Archaeopteryx). The study of organs/ structure of various groups of organism, they conclude that divergent, convergent and parallel evolution has taken place.

Fig. 1: Arrangement of pictures based on Similarities and dissimilarities of different organs and fossils to study Evolution (Arranged by the KRPs)

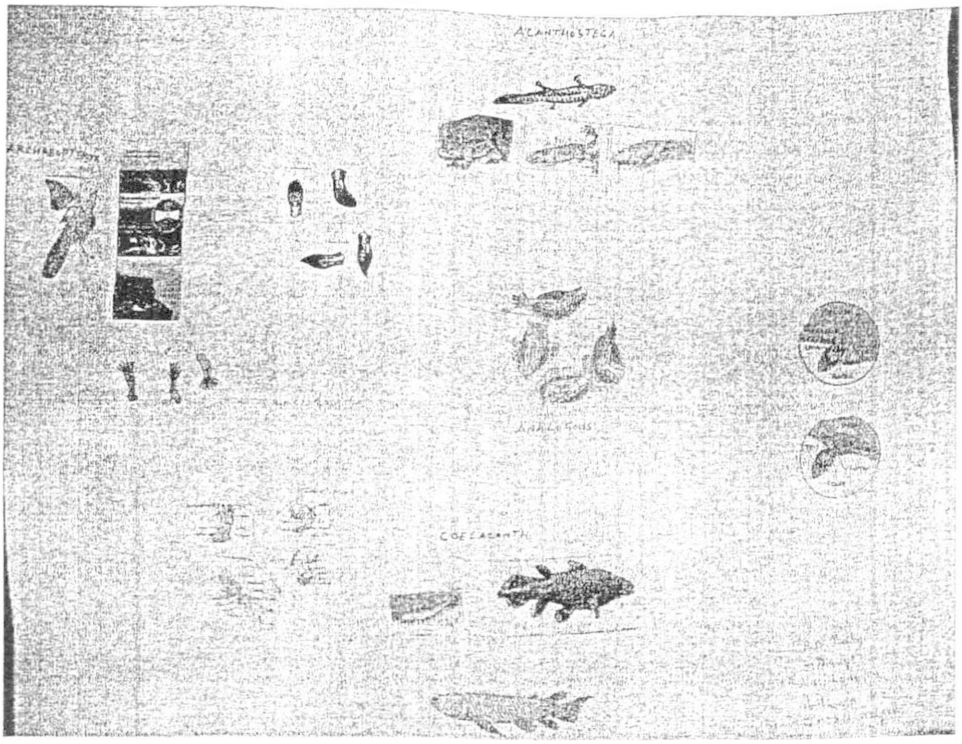


Fig. 2: Arrangement of pictures based on Similarities and dissimilarities of different organs and fossils to study Evolution (Arranged by the KRPs)

Activity 2: Observe the ear lobe feature (attached/ free), collect the data on the particular trait assigned.

An elaborate discussion was held about the dominant and recessive genes their phenotypical expression. The same was attributed to the observation regarding the ear lobe data tabled.

Topic: Diversity in Living Organisms (Class IX Science)

Date: March 14, 2014 (IV Session – 3.45 – 5.15 PM)

By Dr. Vareishang Tangpu, Assistant Professor in Zoology, RIE, Mysore

INTRODUCTION

Biodiversity is a short form for 'biological diversity', it describes the variety of all life forms on earth and all the places where it is found. "Biodiversity" is most commonly used to replace the more clearly defined and long established terms, species diversity and species richness. Biologists most often define biodiversity as the "totality of genes, species, and ecosystems of a region".

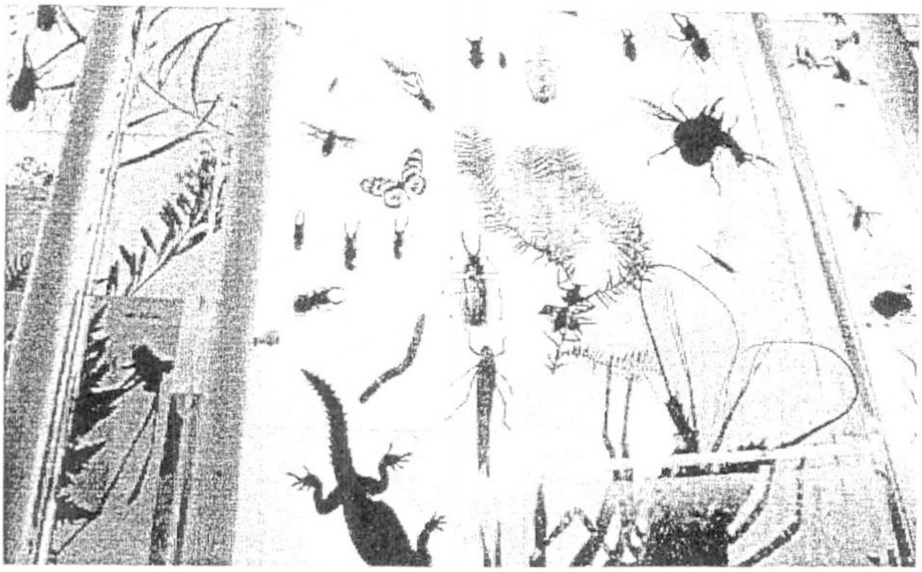
The training was intended to motivate the KRPs to understand diversity in living organisms, and to bring awareness about biodiversity and promote sustainable development initiates, to preserve biodiversity of the school premises. Biodiversity provides essential ecosystem services maintaining life and supporting it.

Diversity in Living Organisms

Living organisms include the smallest micro-organisms to largest animals and plants. They live on this habitat 'Earth' together with different habitats, habits, sizes, numbers, colours, shapes, lifespan etc. It is humanly impossible to study every species on this earth. Therefore, it is an attempt to study the living organisms by arranging them in a very convenient and easy way in naming, classifying, grouping and characterizing them.

ACTIVITY 1: Diversity of organisms

ENGAGING: How many numbers of different living organisms are countable in this picture?

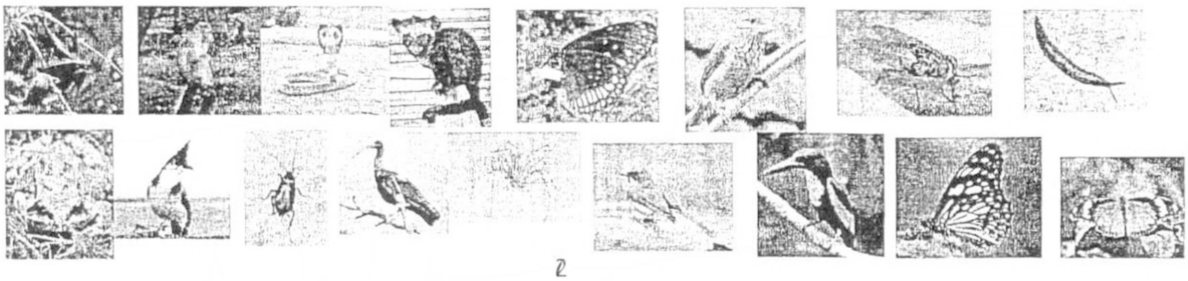


The KRPs counted and concluded it was 10, another said it was 12 and still others answered it was 5.

EXPLAINING: The total number of species living on the planet is imprecisely known, and it is assumed the total species could be over 100 millions. This is because there are large numbers of species yet undiscovered and undescribed. The total number of known species including all animals, plants and micro-organisms is about 1.4 million, and over half of these are insects.

Taxonomists have fairly complete records for the best known groups (e.g. birds with 9, 881 species world-wide). It is now also reasonably clear where the main gaps in our knowledge are, and intensive sampling of species-rich groups (e.g. insects) and species-rich areas (e.g. moist tropical forests) is now taking place to provide a more reliable picture of global and regional species richness, and a stronger basis for estimating the number of species.

EXPLORING: Arrange the following organisms in any fashion you want



EXPLANATION: In order to study the enormous diversity of organisms they need to be organised into manageable groups. This grouping of organisms is known as **classification** and the study of biological classification is called **taxonomy**. The usual method of classifying organisms, although not the only one in existence, follows the system originally proposed by the Swedish naturalist **Carl Linnaeus** (1707-1778) who gave each organism a two-part **scientific name** - a genus name and the species name (e.g. *Homo sapiens*). It is a hierarchical system of groupings based on evolutionary relationships. The sequence in the hierarchy is as follows:

1. Kingdom
2. Phylum
3. Class
4. Order
5. Family
6. Genus
7. Species

EXTENDING: The five major groups, or **kingdoms**, are outlined below:

I. **Bacteria Kingdom:** Only organisms visible under the high power of the light microscope. Unlike other organisms (which have eukaryotic cells), they are single **prokaryotic cells**, i.e. without a proper nucleus (the DNA is not protected by a nuclear membrane), and live just about everywhere - air, water, soil, or inside animals and plants. They are often categorised according to their shape: spherical (cocci) bacteria, rod-shaped (bacilli) bacteria. Many are beneficial, others cause disease.

II. **Protoctist Kingdom:** A wide range of organisms divided into two main groups: **single-celled protoctists** which are larger than bacteria and usually visible under the low power of the microscope. They may be plant-like, feeding by photosynthesis (e.g. *Euglena* in ponds; *Pleurococcus* on trees), or animal- like, taking in organic food (e.g. *Amoeba* and *Paramecium* in ponds). They live mainly in water or inside other organisms. **algae** (e.g. seaweeds; *Spirogyra* blanket weed in ponds) are simple multicellular organisms without definite roots, stems or leaves. They are photosynthetic and live mainly in water.

III. **Fungus Kingdom:** Single-celled (e.g. yeast), or multicellular (e.g. mushrooms, and moulds such as *Penicillium* and bread mould) which grow from a network (**mycelium**) of interwoven threads called **hyphae**. The hyphae have nuclei, and cell walls containing chitin, not cellulose. They have no chlorophyll and feed saprophytically absorbing organic substances.

[NB **Viruses** do not fit into any of the five kingdoms. They are smaller than bacteria and consist of genetic material (DNA or RNA) enclosed in a protein coat. They are able to replicate themselves inside other living cells, but are generally not considered living as they do not show many of the characteristics that define a living organism.]

IV. **Plant Kingdom:** The term plant, in everyday usage, generally refers to a complete, herbaceous specimen. Some children have difficulty assigning trees, or parts of plants (such as fruits, vegetables, flowers or seeds) to the plant kingdom. Plants are multicellular organisms able to photosynthesise. They have cells with cell walls, nuclei and chloroplasts. The largest, most highly evolved and most familiar group is the phylum of **flowering plants** (angiosperms). These have flowers for reproduction, produce seeds protected inside fruits, and range from small grasses to huge trees (e.g. oak, sycamore, fruit trees). The other phyla are non-flowering, often less conspicuous plants: the **non-flowering trees** (conifers) produce seeds in cones (e.g. pine, cypress); **ferns** (pteridophytes) can be large (e.g. bracken in woods) or small (e.g. water ferns in ponds), they have roots, stems and leaves (called fronds) and reproduce by spores; **mosses** and **liverworts** (bryophytes) are small plants with tiny leaves one cell thick and single- celled rootlets, reproduce by spores, common on trees, soil, walls, edges of ponds, etc.

V. **Animal Kingdom:** There is a tendency for children to only regard large land mammals as animals. The animal kingdom includes organisms as diverse as humans (including babies and children!), fish, worms and limpets. Animals are multicellular, heterotrophic organisms. Their cells are without cell walls, but enclosed within a cell membrane. They have a nervous system and are usually able to move themselves around.

EVALUATION

QUESTION 1: *What kinds of predators live in the woods around campus?*

RESPONSES:

- birds, insects and animals
- pigeons
- snakes, poisonous spiders and crocodiles
- venus fly traps

QUESTION 2: *What would happen to the other living things if all the foxes died?*

RESPONSES:

- nothing!
- the rabbits would be happy and more would grow
- the rabbits would grow bigger

QUESTION 3: *Why are there more rabbits than foxes?*

RESPONSES:

- so the foxes don't get hungry
- because there's lots of grass
- because someone feeds them
- because rabbits have lots of babies

QUESTIONS: *How come the dead plants and animals in the woods disappear?*

RESPONSES:

- they just disappear!
- birds and mice eat them
- they rot, then insects eat them
- people bury them
- they go into the soil and fertilise it, and keep making the soil deeper

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Further activities (Optional) may be carried out to study "diversity" as follows:

ACTIVITY 2: IDENTIFICATION OF BIRDS BY BILLS/BEAKS

Objective: Students will observe different types of beaks of birds and relate these to the bird's method of feeding.

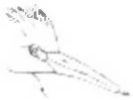
Materials: Lab paper, pictures of birds, pencil

Procedure:

1. Look at the pictures of the birds. Examine the beak of each bird and determine the type of each beak based on its shape and function. Some beak types may be used more than once.
2. Place your choices on the chart in the column marked **Beak for**: (Some of the same beaks may be found on different birds).

Students are encouraged to observe different types of beaks. You may ask, "Did you ever wonder why there are so many types of bird beaks (Ornithologists call them bills)"? The most important function of a bird bill is feeding, and it is shaped according to feeding habits. You can use the type of bill as one of the characteristics to identify birds. Here are some common bill shapes and the food they are especially adapted to eat:

SHAPE	TYPE	ADAPTATION
	Cracker	Seed eaters like sparrows and cardinals have short, thick conical bills for cracking seed.
	Shredder	Birds of prey like Black Kite, hawks and owls have sharp, curved bills for tearing meat.
	Chisel	Woodpeckers have bills that are long and chisel-like for boring into wood to eat insects.

	Probe	Sunbird, Hummingbird bills are long and slender for probing flowers for nectar.
	Strainer	Some ducks have long, flat bills that strain small plants and animals from the water.
	Spear	Birds like herons and kingfishers have spear-like bills adapted for fishing.
	Tweezer	Insect eaters like warblers have thin, pointed bills.
	Swiss Army Knife	Crows have a multi-purpose bill that allows them to eat fruit, seeds, insects, fish, and other animals.

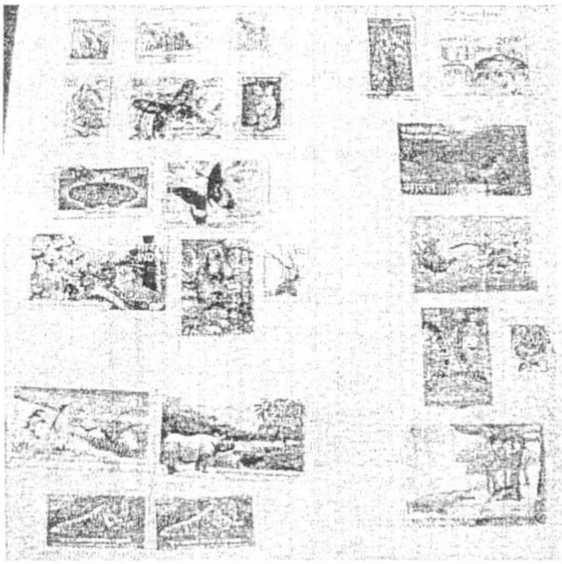
ACTIVITY 3: VISIT TO NATIONAL PARK/ BIODIVERSITY RESERVATION

Objectives:

- *To collect animal photos and record their food habits/record their voices in tape recorder,*
- *To write common names of all animals and*
- *To take photos which you come across in your day to day life and*
- *To understand how much are you dependent on those animals/for which products:*
  - *Cow*
  - *Goat*
  - *Buffalo*
  - *Hen*
  - *Chick*
  - *Tiger*
  - *Bear*
  - *Deer*
  - *Lion*
  - *Fox*

ACTIVITY 4: COLLECTION OF STAMPS OF PLANTS AND ANIMALS

An example is depicted for the sake of children. You can collect stamps of any country, including that of India, to cultivate the hobby of philately. Good quality stamps can be exhibited in competition conducted by Indian Postal Department or Government of India's philatelic displays.



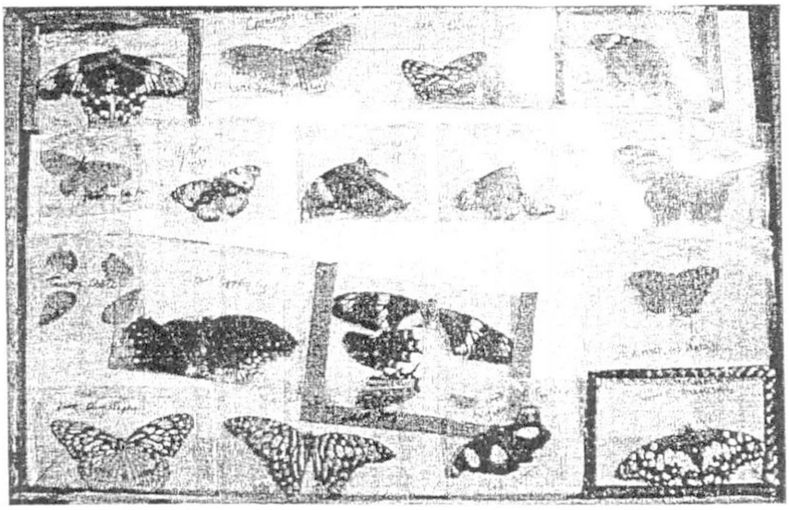


Fig. A collection of butterflies from RIE Campus – which was shown to the KRPs to study the diversity of butterflies

Lesson Plan

Topic : Linear equations in two variables
Unit : Algebra
Name of the Teacher: Dr. B.S.P. RAJU.

Class: IX Std.
Time: 45 minutes
Date: 7-2-2012

Instructional Objectives:

At the end of the class students will be able to:

i. States the definition of liner equations in two variables
ii. State the characteristics for an equation to be linear equation in two variables.
iii. Cites example for the linear equations in two variables.
iv. Identify linear equations in two variables.
v. Formulates the linear equations in two variables.

Previous Knowledge:

i. Examples of linear equations in one variable
ii. Conditions on equations to be linear in one variable
iii. Formulation of linear equations in one variable.

Teaching points:

i. Linear equations in two variables is an equation that contains two different variables each of degree one.
ii. General form of linear equation in two variable, is $ax + by + c = 0$, where a, b and c are real numbers, with a and b both not equal to zero.

Teaching aids: Nil

Expected learning outcomes	Sequential Learning Activities with in built evaluation	Evaluation/Blackboard work
	1. T: Good morning 2. S3: Very good morning Sir 3. T: In your earlier classes you have learnt linear equations -in one variable. Give a few examples for linear equations in one variable.	
Recalls examples for linear equations in one variable	4. S10: $x + 5 = 0$ $y - 2 = 0$ $2z = 6$ 5. T: Why do they are called linear equations	$x + 5 = 0$ $y - 2 = 3$ $2z = 6$
States the necessary condition for	6. S16: These are linear equations because, the degree of the variable in	

<table>
<tr><td>equations to be linear</td><td>them is 1.
7. T: How many variables are there in each of the equations</td><td></td></tr>
<tr><td>Identifies the number of variables, in the equations</td><td>8. S6 : One
9. T: Ram and Rahim together have 25 books. Rahim have 5 more books than Ram. Find number of books Ram and Rahim have?
10. S9: Let x to be the number of books Ram have. So Rahim will have x + 5</td><td></td></tr>
<tr><td>Solves the problem by formulating the linear equation in one variable.</td><td>$x + x + 5 = 25$
$2x + 5 = 25$
$2x = 25 - 5 = 20$.ie $x = 10$
So Ram have 10 books Rahim have 10 + 5 = 15 books.

11. T: Good.. See here on the black board a set of equations given in one column as set A and in other column as set B.

All the equations in set A has something common which is not found in each of the equations of set B. Observe and tell me what is that?</td><td><table>
<tr><th>Set A</th><th>Set B</th></tr>
<tr><td>1) $x + 2y = 3$</td><td>$x-y+z=8$</td></tr>
<tr><td>2) $2r+5s=0$</td><td>$n=5$</td></tr>
<tr><td>3) $u = 2v+4$</td><td>$u+v+t=0$</td></tr>
<tr><td>4) $x-2z=6$</td><td>$2x+y+u+3=5$</td></tr>
<tr><td>5) $3t=5u-8$</td><td>$x+8u=3z$</td></tr>
</table>
Table – 1</td></tr>
<tr><td>Compare each of equations in set A & contrasts with equations in B and states the findings.</td><td>12. S7: Equations in set A contains two variables whereas the equations in set B have either 1 or more than 2 variables.

13. T: Yes good in set A, each of the equations contain two variables.

14. T: Now observe the equations in table – 2. see the each of the</td><td><table>
<tr><th>Set A</th><th>Set B</th></tr>
<tr><td>1) $x + 2 = 0$</td><td>$x^2 - 5=3$</td></tr>
<tr><td>2) $x + y = 5$</td><td>$X^2+Y^2=4$</td></tr>
<tr><td>3) $u = 2v+4$</td><td>$r+2s^2 = 0$</td></tr>
<tr><td>4) s-2t+56</td><td>$r^2 +2t - u^3= 9$</td></tr>
</table>
Table – 2</td></tr>
</table>

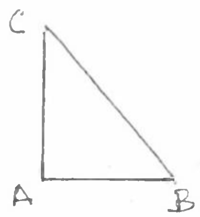
(2)

	equations in set A has some thing common and which is not found in every equation of the set B. Try to find that.	
Compares and contrasts and finds the commonalities in set A.	15. S10: All the variables in each of the equation given in set A are of degree 1, while it is not so in the equations in set B. 16. T: Good. Now any one of you come to black board and write a few equations which contain two variables and each of degree 1.	
Writes the equations	17. S2 : (Writes) x+3y=10 2t+5=3u 18. T: Good. What do you call an equation containing variables of degree 1.	
Recalls from the previous knowledge. Tries to define in his own words	19. S3: It is a linear equation. 20. T: Yes can anyone state what is a linear equation in two variables. 21. S5: A linear equation in two variables is an equation that contains two variables and degree 1. 22. T : Then is this $x + 2y^2 = 5$ a linear equation in two variables.	
Recognises the lack of necessary condition	23. S1: No, Sir, because one of the variable is of degree 2. 24. T : Can any one restates the definition given by S_5	

Modifies the definition given by S_5	25. S_6 A linear equation in two variables is an equation that contains two variables and each of degree 1. 26. T: Yes good. So a linear equation in two variables is an equation having two variables and each of degree 1. 27. T: S7 give two examples of linear equation in two variables.	
Give examples	28. S7 : 1) $15u - t = 0$ 2) $x - 8y = 5$ 29. T: Good. (write an equation on the black board) Is this a linear equation in two variables	$X = 8$
	30. S5 : No 31. T: Why?	
Identifies the lack of necessary condition	32. S5: Because it does not contain two variables. 33. T: (writes) Is this a linear equation in two variables. 34. S8: Yes. 35. T: Why?	$T + 5u = 8$
Identifies the sufficient condition for an equation to be linear in two variables.	36. S8: Because it contain two variables and also each of the variable is of degree 1. 37. T (writes) Is this a linear equation in two variable 38. S5 : No 39. T: Why?	$t^2 = 5$
Identifies lack of necessary condition	40. S5: It is not linear, because the variable is of degree 2.	

Classifies the linear equations in two variables and others	41. T: Yes, for an equation to be linear in two variables it should contain two variables and also each variable should be of degree 1. 42. T: (Writes a set of equations on the black board) write down the equations which are linear in two variables and that are not. 43. S6: Writes. Linear equations in two variables are equations: 1,3, 7 & 10 44. T: Miss. Kalyani has a few hen and a few pigs in hen form. Total legs of the hens and pigs are 50 and the heads are 17. Can you express these in the form of equations. 45. S : (Silence) 46. T: Is one variable enough to represent the situation. 47. S: Looks no. 48. T: Then how many variables will it be better.	1) $x + y = 8$ 2) $2x^2 - y = 4$ 3) $2t + u = 10$ 4) $x^2 - u^2 = t^2$ 5) $x^3 - y^3 = 8$ 6) $x + y = 2t$ 7) $s + 2u = -8$ 8) $r + s^2 = t^2$ 9) $a + b = c$ 10) $5a + 6b = 9$
Identifies the variables	49. S: May be we require two variables one for pigs and one for hens. So let the number of hens be x and the number of pigs be y. 50. T: Then how many heads each one of the hen and the pigs has,	

8

	51. S: Each one has one head. 52. T: How many heads x hens and y pigs have.	
Represents in the form of an equation.	53. S: x x 1 + y + 1 = x + y But it is given equal to 17 x + y = 17 54. T: Now can you represent the legs of the hen and pigs in equation form. 55. S: 2x + 4y = 50 56. T: Each student in IX class has 4 text books and 6 Note books and each student in V class has 2 text books 2 Note books. Total number of text books are 100 and the note books are 140 can you represent these in the form of equations.	
Represents the data in the form of equation	57. S: Let x be the no. of IX class students and let y be the no. of V class students. then 4x + 2y = 100 6x + 2y = 140 58 T: In a right angled triangle, write the equation representing the sum of the other two angles (besides the right angle) What are the variables? 59 S16 : $\angle B + \angle C = 90^{\circ}$ 60 T: Do this problem at your home.	

(6)

	Prabhakar has a few Rs. 5/- notes and a few Rs. 10/- notes. Total value of the money is 125. Can you express this as a linear equation in two variables.	

The dialogue nos.	Description
3-4	Review of prerequisite number (i)
5-8	Review of prerequisite number (ii)
9-10	Review of prerequisite number (iii)
11-13	Identifying one of the essential attribute of the concept.
14-15	Identifying of other essential attribute of the concept.
16-17	Eliciting the examples of the concept without formally defining
18-21	Eliciting the definition of the concept in their own words using the previous knowledge (18-19).
22-25	Teacher correcting the students definition by giving a counter example in dialogue 22.
26	Teacher confirming the definition given by the student by restating with an appreciation
-	Achieved the objective (1)
27-28	Eliciting the examples of the concept using the definition of the concept
	Note the difference between the dialogues 16-17 and 27-28. In 16-17 it is te examples but it is in the process of defining the concept whereas in 27-28 it is the examples of the concept.
29-32	Giving a non example with one of the attribute missing and eliciting a reason for it being a non example.
33-36	Giving an example and eliciting the reasons for it being an example.
37-40	Giving a non example with another attribute missing and eliciting a reason for it being a non example
41	Giving the essential attributes of the concept Attained the objective (ii)
42-43	Identifying the equations which are linear in two variables
44-45	Formulating linear equation in two variables
56-57	Evaluating the formulation of the linear equations in two variables

Attained the objective (V)

Strategy for linear equation into two variables
Compare and contrasts (11-15) -- Defines (16-26) – gives examples (27-28) __ non example with a reason (29-32) – example with a reason (33-36) – non example with a reason (37-40) – sufficient condition (41) – classifies (42-43)

Strategy for formulating linear equation in two variables.
Example (44-45) – evaluation (55-57)

Introducing the topic by reviewing the pre-requisites (1-10) Development of the lesson. (11-57)
Review (58)
Assignment (60)
Note: Numbers are the serial number of the dialogues.

Those Who Understand: Knowledge Growth in Teaching
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Those Who Understand: Knowledge Growth in Teaching

LEE S. SHULMAN
Stanford University

*"He who can, does.
He who cannot, teaches."*

I don't know in what fit of pique George Bernard Shaw wrote that infamous aphorism, words that have plagued members of the teaching profession for nearly a century. They are found in "Maxims for Revolutionists," an appendix to his play *Man and Superman*. "He who can, does. He who cannot, teaches" is a calamitous insult to our profession, yet one readily repeated even by teachers. More worrisome, its philosophy often appears to underlie the policies concerning the occupation and activities of teaching.

Where did such a demeaning image of the teacher's capacities originate? How long have we been burdened by assumptions of ignorance and ineptitude within the teaching corps? Is Shaw to be treated as the last word on what teachers know and don't know, or do and can't do?

Yesterday's Examinations

We begin our inquiry into conceptions of teacher knowledge with the tests for teachers that were used in this country during the last century at state and county levels. Some people may believe that the idea of testing teacher competence in subject matter and pedagogical skill is a new idea, an innovation spawned in the excitement of this era of educational reform, and encouraged by such committed and motivated national leaders as Albert Shanker, President, American Federation of Teachers; Bill Honig, State Superintendent of Schools, California; and Bill Clinton, Governor of Arkansas. Like most good ideas, however, its roots are much older.

Among the most fascinating archives in which to delve are the annual reports of state superintendents of education from over a century ago, in which we find copies of tests for teachers used in licensing candidates at the county level. These tests show us how teacher knowledge was defined. Moreover, we can compare those conceptions with their analogues today. I have examined tests from Massachusetts, Michigan, Nebraska, Colorado, and California. Let us take as a representative example the California State Board examination for elementary school teachers from March 1875 and first look at the categories the examination covered:

1. Written Arithmetic
2. Mental Arithmetic
3. Written Grammar
4. Oral Grammar
5. Geography
6. History of the United States
7. Theory and Practice of Teaching
8. Algebra
9. Physiology
10. Natural Philosophy (Physics)
11. Constitution of the United States and California
12. School Law of California
13. Penmanship
14. Natural History (Biology)
15. Composition
16. Reading
17. Orthography
18. Defining (Word Analysis and Vocabulary)
19. Vocal Music
20. Industrial Drawing

The total number of points possible on this day-long essay examination was 1,000. The examiners were instructed to score for the correctness of responses and to deduct points for errors of composition, grammar, or spelling. What kinds of questions were asked on the examination? We shall review some from several of the categories.

- Find the cost of a draft on New York for $1,400 payable sixty days after sight, exchange being worth 102 1/2 percent and interest being reckoned at a rate of 7 percent per annum. (Written Arithmetic, one of ten items)
- Divide 88 into two such parts that shall be to each other as 2/3 is to 4/5. (Mental Arithmetic, one of ten items)
- When should the reciprocal pronouns *one another* and *each other* be used? the correlative conjunctions *so as* and *as as*?
- Name and illustrate five forms of conjugation. Name and give four ways in which the nominative case may be used. (Grammar, two of ten items)
- Define *specific gravity*. Why may heavy stones be lifted in water when on land they can scarcely be moved?
- What is adhesion? What is capillary attraction? Illustrate each. (2 of 10 items from Natural Philosophy)
- Name five powers vested in Congress.

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Lee S. Shulman is Professor of Education and Affiliate Professor of Psychology at the School of Education, Stanford University, Stanford, CA 94305. His specializations are teacher education and the cognitive psychology of instruction.

Lest you think that all of the items on the 1875 California Teachers Examination deal with subject matter alone, rest assured that there is a category for pedagogical practice. However, only 50 out of the total 1,000 possible points are given over to the 10-item subtest on Theory and Practice of Teaching. Examples of those items are:

- What course would you pursue to keep up with the progress in teaching?
- How do you succeed in teaching children to spell correctly the words commonly misspelled?
- How do you interest lazy and careless pupils? Answer in full (!).

All the tests I have found from that period follow the same pattern. Ninety to ninety-five percent of the test is on the content, the subject matter to be taught, or at least on the knowledge base assumed to be needed by teachers, whether or not it is taught directly. Thus, aspects of physiology are apparently deemed necessary because of the expectation that teachers understand the biological functioning of their pupils.

How closely did the actual tests administered resemble these I have read? What was it like to take one of these examinations? A useful source for addressing such questions is the autobiographical literature by teachers, one of the most useful compendia of which is *Women's "True" Profession*, a collection of excerpts from the diaries or memoirs of women teachers. Among these, we find the following reminiscence of Lucia Downing (cited in Hoffman, 1981). She reported on the taking of her initial county examination in 1881, as administered by her family physician, who also served one day per month as county superintendent.

> When my sister, already a teacher, went to take another examination, the spring I was thirteen, I went along too, and said to the doctor, who was only a superintendent that day, that, if he had enough papers, I should like to see how many questions I could answer. The doctor smiled at me, and gave me an arithmetic paper for a starter. It proved to be easy, for it brought in some favorite problems in percentage, which would be an advantage to a merchant, as they showed how to mark goods in such a way that one could sell below the marked price, and still make a profit. I guess all merchants must have studied Greenleaf's *Arithmetic*! There was another problem under the old Vermont Annual Interest Rule... and then proudly started on Grammar. I knew I could do something with that, for I loved to parse and analyze and "diagram," according to Reed and Kellogg. In fact, my first knowledge, and for many years my only knowledge of "Paradise Lost" was gleaned from a little blue parsing book....
>
> Next came Geography. Though I had never traveled farther than Burlington, I knew, thanks to Mr. Guyot and his green geography, that Senegambia was "rich in gold, iron ore and gum-producing trees." ... History and Civil Government were pretty hard for me, but next came Physiology, and I made the most of my bones and circulatory system, hoping to impress the physician. But it was in Theory and School Management that I did myself proud. I discoursed at length on ventilation and temperature, and knowing that "good government" is a most desirable and necessary qualification for a teacher, I advocated a firm, but kind and gentle method, with dignity of bearing. In giving my views of corporal punishment, I related a story I had read of the Yankee teacher who was asked his views on the subject. He said, "Wal, moral suasion's my theory, but lickin's my practice! "....
>
> Finally, one morning, there was an envelope addressed in Dr. Butler's scholarly hand... (and) out fluttered two yellow slips—two certificates, entitling the recipients to teach in Vermont for one year. And one was in my name! I cannot recall any subsequent joy equal to what I felt at that moment—even a college diploma and a Phi Beta Kappa key, in later years, brought less of a thrill (pp. 29–30).

The assumptions underlying those tests are clear. The person who presumes to teach subject matter to children must demonstrate knowledge of that subject matter as a prerequisite to teaching. Although knowledge of the theories and methods of teaching is important, it plays a decidedly secondary role in the qualifications of a teacher.

Today's Standards

The emphasis on the subject matter to be taught stands in sharp contrast to the emerging policies of the 1980's with respect to the evaluation or testing of teachers. Nearly every state is reexamining its approaches to defining what teachers must know to be licensed and subsequently tenured. Many states have introduced mandatory examinations, but these do not typically map onto the content of the curriculum. They are tests of basic abilities to read, write, spell, calculate, and solve arithmetic problems. Often they are treated as prerequisites for entry into a teacher education program rather than as standards for defining eligibility to practice.

In most states, however, the evaluation of teachers emphasizes the assessment of capacity to teach. Such assessment is usually claimed to rest on a "research-based" conception of teacher effectiveness. I shall take as my example a list of such competencies prepared by a state that I briefly advised during its planning for a state-wide system of teacher evaluation. The following categories for teacher review and evaluation were proposed:

1. Organization in preparing and presenting instructional plans
2. Evaluation
3. Recognition of individual differences
4. Cultural awareness
5. Understanding youth
6. Management
7. Educational policies and procedures

As we compare these categories (which are quite similar to those emerging in other states) to those of 1875, the contrast is striking. Where did the subject matter go? What happened to the content? Perhaps Shaw was correct. He accurately anticipated the standards for teaching in 1985. He who knows, does. He who cannot, but knows some teaching procedures, teaches.

Yet policymakers justify the heavy emphasis on procedures by referring to the emergent research base on teaching and teaching effectiveness. They regularly define and justify these categories by the extremely powerful phrase "research-based teacher competencies." In what sense can it be claimed that such a conception of teaching competence is research based?

The designers of recent approaches to teacher evaluation cite the impressive volume of research on teaching effectiveness as the basis for their selection of domains and standards, and in fact, this basis is valid. They base their categories and standards on a growing body of research on teaching, research classified under the rubrics of "teaching effectiveness," "process-product studies," or "teacher behavior" research. These studies were designed to identify those patterns of teacher behavior that accounted for improved academic performance among pupils.

Whether by contrasting more effective with less effective teachers, or by conducting experiments in which teachers were trained to employ specific sets of teaching behaviors and monitoring the results for pupil achievement, this research program has yielded findings on the forms of teacher behavior that most effectively promote student learning. The work has been criticized from several perspectives, both technical and theoretical, but for our purposes I would consider the research program a thriving and successful one (Shulman, 1986).

Nevertheless, policymakers' decision to base their approaches to teacher evaluation standards on this work is simultaneously the source of their greatest strength and their most significant weakness. What policymakers fail to understand is that there is an unavoidable constraint on any piece of research in any discipline (Shulman, 1981). To conduct a piece of research, scholars must necessarily narrow their scope, focus their view, and formulate a question far less complex than the form in which the world presents itself in practice. This holds for any piece of research; there are no exceptions. It is certainly true of the corpus of research on teaching effectiveness that serves as the basis for these contemporary approaches to teacher evaluation. In their necessary simplification of the complexities of classroom teaching, investigators ignored one central aspect of classroom life: the subject matter.

This omission also characterized most other research paradigms in the study of teaching. Occasionally subject matter entered into the research as a context variable—a control characteristic for subdividing data sets by content categories (e.g., "When teaching 5th grade mathematics, the following teacher behaviors were correlated with outcomes. When teaching 5th grade reading, . . . "). But no one focused on the subject matter content itself. No one asked how subject matter was transformed from the knowledge of the teacher into the content of instruction. Nor did they ask how particular formulations of that content related to what students came to know or misconstrue (even though that question had become the central query of cognitive research on *learning*).

My colleagues and I refer to the absence of focus on subject matter among the various research paradigms for the study of teaching as the "missing paradigm" problem. The consequences of this missing paradigm are serious, both for policy and for research.

Policymakers read the research on teaching literature and find it replete with references to direct instruction, time on task, wait time, ordered turns, lower-order questions, and the like. They find little or no references to subject matter, so the resulting standards or mandates lack any reference to content dimensions of teaching. Similarly, even in the research community, the importance of content has been forgotten. Research programs that arose in response to the dominance of process-product work accepted its definition of the problem and continued to treat teaching more or less generically, or at least as if the content of instruction were relatively unimportant. Even those who studied teacher cognition, a decidedly non-process/product perspective, investigated teacher planning or interactive decisionmaking with little concern for the organization of content knowledge in the minds of teachers. I shall have more to say about the missing paradigm and its investigation a bit later. Let us now return to the question with which we began.

Content and Pedagogy in the History of the Academy

Why this sharp distinction between content and pedagogical process? Whether in the spirit of the 1870s, when pedagogy was essentially ignored, or in the 1980s, when content is conspicuously absent, has there always been a cleavage between the two? Has it always been asserted that one either knows content and pedagogy is secondary and unimportant, or that one knows pedagogy and is not held accountable for content?

I propose that we look back even further than those 1875 tests for teachers and examine the history of the university as an institution to discern the sources for this distinction between content knowledge and pedagogical method.

In *Ramus, Method and the Decay of Dialogue*, Father Walter Ong (1958) presents an account of teaching in the medieval university in a chapter with the captivating title "The Pedagogical Juggernaut." He describes a world of teaching and learning in those universities, where instead of separating content and pedagogy (what is known from how to teach it), no such distinction was made at all. Content and pedagogy were part of one indistinguishable body of understanding.

To this day, the names we give our university degrees and the rituals we attach to them reflect those fundamental connections between knowing and teaching. For example, the highest degrees awarded in any university are those of "master" or "doctor," which were traditionally interchangeable. Both words have the same definition; they mean "teacher." "Doctor" or "dottore" means teacher; it has the same root as "doctrine," or teaching. Master, as in school master, also means teacher. Thus, the highest university degree enabled its recipient to be called a teacher.

Ong's (1958) account of these matters is enlightening:

> The universities were, in principle, normal schools, not institutions of general education. This was true of all faculties: arts, medicine, law, and theology; and it was most true at Paris and at universities modeled on Paris (rather than on Bologna), such as Oxford and Cambridge and, later, the German universities. Such universities were

in brief, medieval guilds, or were composed of four teachers' guilds or faculties with their associated pupils. The degree of master or doctor (the terms were equivalents, varying from university to university or from faculty to faculty) was the formal admission to the guild, just as the bachelorship which preceded it was admission to the body of apprentice teachers.

. . . Officially, the bachelor of arts was an apprentice teacher on the arts faculty; bachelors of theology were apprentice teachers of theology, condemned to a long round of "practice" teaching; and bachelor butchers were apprentice butchers—for all these people were members of their respective trade guilds.

. . . A physician whom a university faculty certifies as a practitioner of medicine is called a "doctor" of medicine, as though he were going to teach medicine, just as in some countries, one trained to practice the law is also called "master" or its equivalent. Graduation, too, is still a "commencement" or *inceptio*—in theory, the beginning of a teaching career. (pp. 153–154)

The *inceptio* of which Ong writes was the ceremony of doctoral examination—the final stage of demonstration that one possessed the necessary capacities for the highest university degree. The basic structure of the examination has remained constant to this day in the final oral examination for the doctorate. The purpose of the examination is to demonstrate that the candidate possesses the highest levels of subject matter competence in the domain for which the degree is awarded. How did one demonstrate such understanding in medieval times? By demonstrating the ability to *teach* the subject (Ong, 1985):

Arrived at the cathedral, the licentiate delivered a speech and read a thesis on some point of law, which he defended against opponents who were selected from among the students, the candidates thus playing for the first time the part of a doctor in a university disputation. (pp. 227–228)

Consider the still current form of the oral exam. First, the candidate presents a brief oral exposition of the thesis. He then defends the thesis in dialogue with the examiners. These parallel the two modes of teaching: the lecture and the disputation. The oral examination is the ultimate test of subject matter expertise; it examines the candidate's ability to teach the subject by employing the dual method of lecture and discussion.[1]

The universities were, therefore, much like normal schools: institutions for preparing that most prestigious of professionals, the highest level of scholar, the teacher. The tradition of treating teaching as the highest demonstration of scholarship was derived from the writings of a far greater authority than George Bernard Shaw on the nature of knowledge. Aristotle, whose works formed the heart of the medieval curriculum, made these observations in *Metaphysics* (cited in Wheelwright, 1951).

We regard master-craftsmen as superior not merely because they have a grasp of theory and *know* the reasons for acting as they do. Broadly speaking, what distinguishes the man who knows from the ignorant man is an ability to teach, and this is why we hold that art and not experience has the character of genuine knowledge (episteme)—namely, that artists can teach and others (i.e., those who have not acquired an art by study but have merely picked up some skill empirically) cannot. (p. 69)

We thus find in Aristotle a very different view of the relationship between knowing and teaching than we find in either Shaw or in the criteria for certification and licensure in some of our sovereign states.

Lest my readers conclude that the medieval university was a pedagogical utopia, to whose practices we need only return to redress the imbalances that plague contemporary teaching policies, permit me to provide a couple of counterexamples. From the classic treatise on the medieval university, Rashdall's (1895/1936) *The Universities of Europe in the Middle Ages*, relates how problems of accountability were handled.

Punctuality is enforced with extreme rigour. The professor was obliged to begin his lecture when the bells of St. Peter's began to ring for mass, under a penalty of 20 solidi for each offence, though he has the privilege of beginning at an earlier hour if he pleases; while he is forbidden to continue his lecture one minute after the bell has begun to ring for tierce. To secure the observance of the statute a more effectual means is adopted even than that of fining the doctor: his pupils are required under a penalty of 10 solidi to leave the lecture-room as soon as the bell begins.

Even in the actual conduct of his lectures the doctor is regulated with the precision of a soldier on parade or a reader in a French public library. He is fined if he skips a chapter or decretal: he is forbidden to postpone a difficulty to the end of the lecture lest such a liberty should be abused as a pretext for evading it altogether. In medieval as in modern times lecturers had a tendency to spend a disproportionate time over the earlier portions of a book, and so leave none for the rest. With a view to checking this practice, an expedient was adopted at Bologna which became universal in the law-universities of Southern Europe. The law-texts were divided into portions known as *puncta*; and the doctor was required to have reached each *punctum* by a specified date. At the beginning of the academical year he was bound to deposit the sum of 10 Bologna pounds with a banker [the stakeholder was known as the *Depositarius*], who promised to deliver it up at the demand of the rectors: for every day that the doctor was behind time, a certain sum was deducted from his deposit by order of these officials. . . . (pp. 196–197)

The medieval university was therefore hardly a paradise for its teachers, especially in Bologna, where the university was a guild of students that hired teachers (in contrast to the Paris model of a guild of teachers selling services to students). Moreover, it was also deeply flawed by an ultimate liability; it was open only to men and boys. This deficiency may account more than most others for the inability of the medieval university to accomplish as much as one would have hoped.

The Missing Paradigm

We have thus seen that the sharp distinction between knowledge and pedagogy does not represent a tradition dating back centuries, but rather, a more recent development. Moreover, identification of teaching competence with pedagogy alone was not even commonplace during Shaw's time. A century ago the defining characteristic of pedagogical accomplishment was knowledge of content.

The pendulum has now swung, both in research and in policy circles. The missing paradigm refers to a blind spot with respect to content that now characterizes most research on teaching and, as a consequence, most of our state-level programs of teacher evaluation and teacher certification.

In reading the literature of research on teaching, it is clear that central questions are unasked. The emphasis is on how teachers manage their classrooms, organize activities, allocate time and turns, structure assignments, ascribe praise and blame, formulate the levels of their questions, plan lessons, and judge general student understanding.

What we miss are questions about the *content* of the lessons taught, the questions aked, and the explanations offered. From the perspectives of teacher development and teacher education, a host of questions arise. Where do teacher explanations come from? How do teachers decide what to teach, how to represent it, how to question students about it and how to deal with problems of misunderstanding? The cognitive psychology of *learning* has focused almost exclusively on such questions in recent years, but strictly from the perspective of learners. Research on teaching has tended to ignore those issues with respect to teachers. My colleagues and I are attempting to redress this imbalance through our research program, "Knowledge Growth in Teaching."

What are the sources of teacher knowledge? What does a teacher know and when did he or she come to know it? How is new knowledge acquired, old knowledge retrieved, and both combined to form a new knowledge base?

We assume that most teachers begin with some expertise in the content they teach. (This may be an unfounded assumption, and the consequences of varying degrees of subject matter competence and incompetence have become a serious topic of our research as well.) Secondary teaching candidates, in particular, have typically completed a major in their subject speciality.

Our central question concerns the transition from expert student to novice teacher. How does the successful college student transform his or her expertise in the subject matter into a form that high school students can comprehend? When this novice teacher confronts flawed or muddled textbook chapters or befuddled students, how does he or she employ content expertise to generate new explanations, representations, or clarifications? What are the sources of analogies, metaphors, examples, demonstrations, and rephrasings? How does the novice teacher (or even the seasoned veteran) draw on expertise in the subject matter in the process of teaching? What pedagogical prices are paid when the teacher's subject matter competence is itself compromised by deficiencies of prior education or ability?

Our work does not intend to denigrate the importance of pedagogical understanding or skill in the development of a teacher or in enhancing the effectiveness of instruction. Mere content knowledge is likely to be as useless pedagogically as content-free skill. But to blend properly the two aspects of a teacher's capacities requires that we pay as much attention to the content aspects of teaching as we have recently devoted to the elements of teaching process.

In our research, we have focused on the development of secondary teachers in English, biology, mathematics, and social studies. Our participants are all in California, thus each has already completed a bachelor's degree in the subject to be taught or has earned a waiver by examination. We are devoting at least one year, and often two, to the study of each novice teacher. We begin with their year of teacher preparation (which is nearly three-quarters completed as this paper is written) and, whenever possible, we will follow them into their first year of full-time teaching.

Our initial goal has been to trace their intellectual biography—that set of understandings, conceptions, and orientations that constitutes the source of their comprehension of the subjects they teach. This approach to assessing their content knowledge is quite different from the methods typically used to measure teacher content knowledge in the research literature; namely, administering an achievement test and employing a total test score as the index of teacher knowledge.

We follow them closely during this teacher-education year, conducting regular interviews, asking them to read and comment on materials related to the subjects they teach, and observing their instruction after having engaged them in a planning interview. We also gather data on the teacher education program in which they are prepared and the impact of both formal and informal preparation experiences on their pedagogy. Most of these references emerge naturally in the course of frequent conversations during the year.

A number of strategic research sites and key events are particularly illuminating for our understanding of how knowledge grows in teaching. Often a young teacher will be expected to teach a topic that he or she has never previously learned. For example, the biology major encounters a unit on levers and simple machines in a general science course. The English major must teach a novel or play never previously encountered. The political science major with strong preparation in Central America confronts a unit on India or the Middle East. Even the math major encounters such occasions, as when teaching introductory topics in algebra or geometry, topics he or she has not encountered since high school or even earlier. How does the teacher prepare to teach something never previously learned? How does learning *for* teaching occur?

Another strategic site occurs in conjunction with sections of textbooks that the teacher finds problematic, flawed in their conception of the topic, incomplete in their treatment, or inadequate in explanation or use of examples. How are these deficiencies in curriculum materials (which appear to be commonplace) apprehended and dealt with by teachers? How do teachers take a piece of text and transform their understanding of it into instruction that their students can comprehend?

We are not alone in our interest. Prominent among other investigators who are pursuing such questions are Gaea Leinhardt at the Learning Research and Development Center, University of Pittsburgh, and Charles Anderson and

Edward Smith of Michigan State's Institute for Research on Teaching.

A Perspective on Teacher Knowledge

As we have begun to probe the complexities of teacher understanding and transmission of content knowledge, the need for a more coherent theoretical framework has become rapidly apparent. What are the domains and categories of content knowledge in the minds of teachers? How, for example, are content knowledge and general pedagogical knowledge related? In which forms are the domains and categories of knowledge represented in the minds of teachers? What are promising ways of enhancing acquisition and development of such knowledge? Because I see these as among the central questions for disciplined inquiry into teacher education, I will now turn to a discussion of some ways of thinking about one particular domain—content knowledge in teaching—and some of the categories within it.

How might we think about the knowledge that grows in the minds of teachers, with special emphasis on content? I suggest we distinguish among three categories of content knowledge: (a) subject matter content knowledge, (b) pedagogical content knowledge, and (c) curricular knowledge.

Content Knowledge. This refers to the amount and organization of knowledge per se in the mind of the teacher. We already have a number of ways to represent content knowledge: Bloom's cognitive taxonomy, Gagné's varieties of learning, Schwab's distinction between substantive and syntactic structures of knowledge, and Peters' notions that parallel Schwab's.

In the different subject matter areas, the ways of discussing the content structure of knowledge differ. To think properly about content knowledge requires going beyond knowledge of the facts or concepts of a domain. It requires understanding the structures of the subject matter in the manner defined by such scholars as Joseph Schwab. (See his collected essays, 1978.)

For Schwab, the structures of a subject include both the substantive and the syntactic structures. The substantive structures are the variety of ways in which the basic concepts and principles of the discipline are organized to incorporate its facts. The syntactic structure of a discipline is the set of ways in which truth or falsehood, validity or invalidity, are established. When there exist competing claims regarding a given phenomenon, the syntax of a discipline provides the rules for determining which claim has greater warrant. A syntax is like a grammar. It is the set of rules for determining what is legitimate to say in a disciplinary domain and what "breaks" the rules.

Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice.

Thus, the biology teacher must understand that there are a variety of ways of organizing the discipline. Depending on the preferred color of one's BSCS text, biology may be formulated as (a) a science of molecules from which one aggregates up to the rest of the field, explaining living phenomena in terms of the principles of their constituent parts; (b) a science of ecological systems from which one disaggregates down to the smaller units, explaining the activities of individual units by virtue of the larger systems of which they are a part; or (c) a science of biological organisms, those most familiar of analytic units, from whose familiar structures, functions, and interactions one weaves a theory of adaptation. The well-prepared biology teacher will recognize these and alternative forms of organization and the pedagogical grounds for selecting one under some circumstances and others under different circumstances.

The same teacher will also understand the syntax of biology. When competing claims are offered regarding the same biological phenomenon, how has the controversy been adjudicated? How might similar controversies be adjudicated in our own day?

We expect that the subject matter content understanding of the teacher be at least equal to that of his or her lay colleague, the mere subject matter major. The teacher need not only understand *that* something is so; the teacher must further understand *why* it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied. Moreover, we expect the teacher to understand why a given topic is particularly central to a discipline whereas another may be somewhat peripheral. This will be important in subsequent pedagogical judgments regarding relative curricular emphasis.

Pedagogical Content Knowledge. A second kind of content knowledge is pedagogical knowledge, which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*. I still speak of content knowledge here, but of the particular form of content knowledge that embodies the aspects of content most germane to its teachability.[2]

Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice.

Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slates.

Here, research on teaching and on learning coincide most closely. The study of student misconceptions and their influence on subsequent learning has been among the most fertile topics for cognitive research. We are gathering an ever-growing body of knowledge about the misconceptions of students and about the instructional conditions necessary to overcome and transform those initial conceptions. Such research-based knowledge, an important component of the pedagogical understanding of subject matter, should be included at the heart of our definition of needed pedagogical knowledge.

Curricular Knowledge. If we are regularly remiss in not teaching pedagogical knowledge to our students in teacher education programs, we are even more delinquent with respect to the third category of content knowledge, *curricular knowledge.* The curriculum is represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances.

The curriculum and its associated materials are the *materia medica* of pedagogy, the pharmacopeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of student accomplishments. We expect the mature physician to understand the full range of treatments available to ameliorate a given disorder, as well as the range of alternatives for particular circumstances of sensitivity, cost, interaction with other interventions, convenience, safety, or comfort. Similarly, we ought to expect that the mature teacher possesses such understandings about the curricular alternatives available for instruction.

How many individuals whom we prepare for teaching biology, for example, understand well the materials for that instruction, the alternative texts, software, programs, visual materials, single-concept films, laboratory demonstrations, or "invitations to enquiry?" Would we trust a physician who did not really understand the alternative ways of dealing with categories of infectious disease, but who knew only one way?

In addition to the knowledge of alternative curriculum materials for a given subject or topic within a grade, there are two additional aspects of curricular knowledge. I would expect a professional teacher to be familiar with the curriculum materials under study by his or her students in other subjects they are studying at the same time.

This lateral curriculum knowledge (appropriate in particular to the work of junior and senior high school teachers) underlies the teacher's ability to relate the content of a given course or lesson to topics or issues being discussed simultaneously in other classes. The vertical equivalent of that curriculum knowledge is familiarity with the topics and issues that have been and will be taught in the same subject area during the preceding and later years in school, and the materials that embody them.

Content Examinations. What might the expectation that our teachers possess these varieties of content knowledge entail for the assessment of teacher competence? If such a conception of teacher knowledge were to serve as the basis for a subject matter content examination for teachers, that examination would measure deep knowledge of the content and structures of a subject matter, the subject and topic-specific pedagogical knowledge associated with the subject matter, and the curricular knowledge of the subject. We would have a form of examination that would be appropriate for assessing the capacities of a *professional.* It would not be a mere subject matter examination. It would ask questions about the most likely misunderstandings of photosynthesis among preadolescents, for example, and the strategies most likely to be useful in overcoming those difficulties. As such, it could distinguish between a biology major and a biology teacher, and in a pedagogically relevant and important way. It would be much tougher than any current examination for teachers.[3]

Forms of Knowledge

A conceptual analysis of knowledge for teachers would necessarily be based on a framework for classifying both the domains and categories of teacher knowledge, on the one hand, and the forms for representing that knowledge, on the other. I would like to suggest three forms of teacher knowledge: *propositional knowledge, case knowledge,* and *strategic knowledge.*

Recall that these are "forms" in which each of the general domains or particular categories of knowledge previously discussed—content, pedagogy, and curriculum—may be organized. (There are clearly other important domains of knowledge as well, for example, of individual differences among students, of generic methods of classroom organization and management, of the history and philosophy of education, and of school finance and administration, to name but a few. Each of these domains is subdivided into categories and will be expressible in the forms of knowledge to be discussed here.)

Much of what is taught to teachers is in the form of propositions. When we examine the research on teaching and learning and explore its implications for practice, we are typically (and properly) examining propositions. When we ask about the wisdom of practice, the accumulated lore of teaching experience, we tend to find such knowledge stored in the form of propositions as well.

The research-based principles of active teaching, reading for comprehension, and effective schools are stated as lists of propositions. The experience-based recommendations of planning five-step lesson plans, never smiling until Christmas, and organizing three reading groups are posed as sets of propositions. In fact, although we often present propositions one at a time, we recognize that they are better understood if they are organized in some coherent form, lodged in a conceptual or theoretical framework that is generative or regenerative. Otherwise they become terribly difficult to recall or retrieve. (The experimental studies of teaching effectiveness have been guilty of presenting lengthy lists of research-based behaviors for teachers to practice, without always providing a rationale or conceptual framework for the set.)

I will argue that there are fundamentally three types of propositional knowledge in teaching, corresponding to the three major sources of knowledge about teaching: disciplined empirical or philosophical inquiry, practical experience, and moral or ethical reasoning. I will refer to these three types of propositions as *principles*, *maxims*, and *norms*.

A principle typically derives from empirical research. One of my favorites is "Ordered turns are associated with higher achievement gains than are random turns in first grade reading groups" (Anderson, Evertson, & Brophy, 1979). The teaching and school effectiveness literatures contain many examples of useful principles for teaching.

The second kind of proposition makes not a theoretical claim, but a practical one. In every field of practice there are ideas that have never been confirmed by research and would, in principle, be difficult to demonstrate. Nevertheless, these maxims represent the accumulated wisdom of practice, and in many cases are as important a source of guidance for practice as the theory or empirical principles. "Never smile until Christmas" would qualify as such a maxim, as would "Break a large piece of chalk before you use it for the first time, to prevent squeaking against the board."

The third kind of proposition reflects the norms, values, ideological or philosophical commitments of justice, fairness, equity, and the like, that we wish teachers and those learning to teach to incorporate and employ. They are neither theoretical nor practical, but normative. They occupy the very heart of what we mean by teacher knowledge. These are propositions that guide the work of a teacher, not because they are true in scientific terms, or because they work in practical terms, but because they are morally or ethically right. The admonitions to provide each student with equal opportunity for turn-taking, or not to embarrass a child in front of peers, are examples of normative knowledge.

The representation of knowledge in the form of propositions has both a distinct advantage and a significant liability. Propositions are remarkably economical in form, containing and simplifying a great deal of complexity. The weakness of propositions is two-fold. First, they become very hard to remember, especially as they aggregate into long lists. This is where theoretical frameworks as intellectual scaffoldings become indispensable. Second, they gain their economy precisely because they are decontextualized, stripped down to their essentials, devoid of detail, emotion, or ambience. Yet, to be remembered and then wisely used, it is precisely the detail and the context that may be needed.

Although principles are powerful, they are not particularly memorable, rendering them a problem to apply in particular circumstances. *How* does a teacher apply, for example, the principle "check for understanding," certainly among the most important in the direct instruction and the active teaching research bases? For these reasons, I am proposing that we look seriously at the usefulness of a second type of knowledge, a necessary complement to knowledge of propositions, *case knowledge*.

The roots of the "case method" in the teaching of law in this country, certainly the best known approach to employing cases as vehicles for professional education, lie in their value for teaching theory, not practice. Christopher Columbus Langdell, who became Dean of the Harvard University Law School in 1870, was responsible for advancing the case method of legal education. His rationale for employing this method was not its value as a way of teaching methods or approaches to practice. He believed that if practice were the essence of law, it had no place in a university. Instead, he advocated the case method of legal education because of its effectiveness in teaching law as science—in teaching legal *theory* through cases.

A case, properly understood, is not simply the report of an event or incident. To call something a case is to make a theoretical claim—to argue that it is a "case of something," or to argue that it is an instance of a larger class. A red rash on the face is not a case of something until the observer has invoked theoretical knowledge of disease. A case of direct instruction or of higher-order questioning is similarly a theoretical assertion. I am therefore not arguing that the preparation of teachers be reduced to the most practical and concrete; rather, using the power of a case literature to illuminate both the practical and the theoretical, I argue for development of a case literature whose organization and use will be profoundly and self-consciously theoretical.

Case knowledge is knowledge of specific, well-documented, and richly described events. Whereas cases themselves are reports of events or sequences of events, the knowledge they represent is what makes them cases. The cases may be examples of specific instances of practice—detailed descriptions of how an instructional event occurred—complete with particulars of contexts, thoughts, and feelings. On the other hand, they may be exemplars of principles, exemplifying in their detail a more abstract proposition or theoretical claim.

Parallel to my argument that there are three types of propositional knowledge of teaching—principles, maxims and norms—I shall propose three types of cases. *Prototypes* exemplify theoretical principles. *Precedents* capture and communicate principles of practice or maxims. *Parables* convey norms or values. Naturally, a given case can accomplish more than a single function; it can, for example, serve as both prototype and precedent.

We are probably most accustomed to thinking of cases as precedents. Knowledge of how a particular teacher taught a particular lesson, or the way a teacher brought a classroom of misbehaving youngsters under control sticks in

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our minds. These remembrances of teachings past are valuable in guiding the work of a teacher, both as a source for specific ideas and as a heuristic to stimulate new thinking. But other kinds of cases exemplify, illustrate, and bring alive the theoretical propositions that are potentially the most powerful tools teachers can have. These are the prototypes within case knowledge. For example, when pharmacology is taught, specific drugs are often used as illustrations. The drugs selected for that purpose are not necessarily the most frequently used in practice. Instead, prototypes are selected that exemplify in their performance the mechanisms of action most characteristic of the *class* of drugs they represent. They are thus theoretically interesting cases for teaching purposes.

As part of an extensive interview study with teachers reputed to be excellent managers of classroom behavior problems, J. Brophy (personal communication, 1981) has reported the following case: A teacher was confronted with repeated incidents of students coming to class without pencils. Rather than either supplying them with replacements (thus making it possible for them to keep up with their work, although running the risk of reinforcing their poor habits) or forcing them to sit through the lesson without benefit of participation, the following strategy was reported. The teacher kept a box of very short pencil stubs in his desk. Whenever a student approached who had forgotten to bring a pencil, the teacher produced the shortest stub available and lent it to the student, who was then expected to use it in completing all of that day's work. In addition to serving as a fine classroom management precedent, this case can also serve as a memorable prototype for the principle of avoiding the inadvertent reinforcement of maladaptive behavior.

Parallel to the theoretical use of prototype cases and the practical use of precedents, we also encounter the moral or normative value of parables. A parable is a case whose value lies in the communication of values and norms, propositions that occupy the very heart of teaching as profession and as craft. Moreover, if we look at the recent literature on effective organizations and what keeps them working well and their members collaborating enthusiastically, we discover the importance of myths in organizations—tales about heroic figures or memorable events that somehow capture the values of those organizations and communicate them to everyone working within them. Those myths, I would argue, or their case equivalents—pedagogical parables—would be equally important in the socialization of teachers into their general professional obligations as well as into the special ethos of particular schools or districts as organizations.

The identification of case knowledge, a case literature, and case-based teacher education as central elements in our discussions and inquiries produces a rich and vital agenda for research. What is involved in the elevation of an event into a case? How are cases aggregated into case knowledge, or alternatively, how does knowledge of cases become case knowledge? How does one learn from and use cases in teaching? If the conception of propositional knowledge is deductive, where applications are deduced from general propositions, how is the analogical reasoning from cases learned, practiced, and tuned? Can we learn from other disciplines or professions such as law or architecture, where analogical reasoning from cases is much more typical, how to conceive of and use case knowledge in education? Why are cases memorable? Is it because they are organized as stories, reflecting the grammar of narrative forms of discourse, that makes them more readily stored, ordered and retrieved than their expository or propositional analogues?[4]

Another reason that these conceptions of case knowledge may be timely is the shift of research paradigms currently underway in our field. We are developing well-reasoned, methodologically sophisticated, and logically argued approaches to the use of qualitative methods and case studies to parallel our already developed approaches of correlational and experimental inquiry. These newer approaches introduce both a new kind of data about which to reason and new modes of reasoning themselves. As Geertz (1983) has observed, "Inquiry is directed at cases or sets of cases, and toward the particular features that mark them off..." (p. 22). As these approaches grow in their educational applications, we will begin to develop a more extensive case literature, as well as a pool of scholars and reflective practitioners capable of preparing and interpreting cases.

Cases are documented (or portrayed) occasions or sets of occasions with their boundaries marked off, their borders drawn. What a given occasion is "a case of" is not immediately apparent from the account itself. Generalizability does not inhere in the case, but in the conceptual apparatus of the explicator. An event can be described; a case must be explicated, interpreted, argued, dissected, and reassembled. A case of Budweiser is marked off from other cases (or non-cases) by physical attributes that are immediately visible. But a case of direct instruction, or of teacher expectations, or of student misconception, is a theoretical construction. Hence, there is no real case knowledge without theoretical understanding. What passes for atheoretical case knowledge is mere anecdote, a parable without a moral.

I am not offering herein an argument against the conception of teaching as skill. I am instead arguing for its insufficiency—its incompleteness as an account of teaching ability and performance. We are only half way toward understanding the knowledge base of teaching when characterizing a research-based conception of the *skills* of teaching. This account must be complemented by a conception of teaching in which the principled skills and the well-studied cases are brought together in the development and formation of *strategic* pedagogical knowledge.

I have referred to *strategic knowledge* as the third "form" of teacher knowledge. Both propositions and cases share the burden of unilaterality, the deficiency of turning the reader or user toward a single, particular rule or practical way of seeing. Strategic knowledge comes into play as the teacher confronts particular situations or problems, whether theoretical, practical, or moral, where principles collide and no simple solution is possible. Strategic knowledge is developed when the lessons of single principles contradict one another, or the precedents of particular cases are incompatible. From Rowe's (1974) research on wait-time, for example, we learn the principle that longer wait-times produce higher levels of cognitive processing. Yet Kounin's (1970) research on classroom management warns the teacher against slowing the pace of the classroom too severely lest the frequency of discipline problems increase. How can the principle of longer wait-times and that of quicker pacing both be correct?

It is in the very nature of the practical or policy fields that individual principles are fated to clash on particular occasions. Knowledge of the relevant propositions and cases is needed to form the underlying knowledge base. Strategic knowledge must be generated to extend understanding beyond principle to the wisdom of practice. We generally attribute wisdom to those who can transcend the limitations of particular principles or specific experiences when confronted by situations in which each of the alternative choices appears equally "principled." Novice bridge players rapidly learn the principles of the game, embodied in such maxims as "Lead fourth highest from your longest and strongest suit," and "Never lead away from a king." But when you must lead away from a king to lead fourth highest, then propositional knowledge alone becomes limited in value. Strategic knowledge (or judgment) is then invoked.[5]

I envision the use of case method in teacher education, whether in our classrooms or in special laboratories with simulations, videodisks and annotated scripts, as a means for developing strategic understanding, for extending capacities toward professional judgment and decision-making. These methods of instruction would involve the careful confrontation of principles with cases, of general rules with concrete documented events—a dialectic of the general with the particular in which the limits of the former and the boundaries of the latter are explored (Shulman, 1984). What happens when cases are applied to principles or principles to cases? What happens when two principles are in conflict, or when two cases yield contradictory interpretations?

When strategic understanding is brought to bear in the examination of rules and cases, professional judgment, the hallmark of any learned profession, is called into play. What distinguishes mere craft from profession is the indeterminacy of rules when applied to particular cases. The professional holds knowledge, not only of how—the capacity for skilled performance—but of what and why. The teacher is not only a master of procedure but also of content and rationale, and capable of explaining why something is done. The teacher is capable of reflection leading to self-knowledge, the metacognitive awareness that distinguishes draftsman from architect, bookkeeper from auditor. A professional is capable not only of practicing and understanding his or her craft, but of communicating the reasons for professional decisions and actions to others (see Shulman, 1983).

This sort of reflective awareness of how and why one performs complicates rather than simplifies action and renders it less predictable and regular. During the eight years that I attended the University of Chicago, I often took classes near Swift Hall, the theology building. On the side of that hall, facing me as I left my classroom building, a saying was carved in the stone: "You shall know the truth and the truth shall make you free." I suppose I never really understood those lines until I realized the implications of knowledge, of deep understanding, for the predictability and uniformity of behavior.

Reinforcement and conditioning guarantee behavior, and training produces predictable outcomes; knowledge guarantees only freedom, only the flexibility to judge, to weigh alternatives, to reason about both ends and means, and then to act while reflecting upon one's actions. Knowledge guarantees only grounded unpredictability, the exercise of reasoned judgment rather than the display of correct behavior. If this vision constitutes a serious challenge to those who would evaluate teaching using fixed behavioral criteria (e.g., the five-step lesson plan), so much the worse for those evaluators. The vision I hold of teaching and teacher education is a vision of professionals who are capable not only of acting, but of enacting—of acting in a manner that is self-conscious with respect to what their act is a case of, or to what their act entails.

The implications of our discussion are several. First, we can begin to conceive differently of how professional examinations for teachers might be organized and constructed. I firmly believe that we must develop professional examinations for teachers, though their existence will constitute no panacea. They must be defined and controlled by members of the profession, not by legislators or layperons. They must reflect an understanding that both content and process are needed by teaching professionals, and within the content we must include knowledge of the structures of one's subject, pedagogical knowledge of the general and specific topics of the domain, and specialized curricular knowledge. Ultimately, that knowledge must be informed by a well-organized and codified case literature. Those tests will be useful when only those who have been professionally prepared as teachers are likely to pass them because they tap the unique knowledge bases of teaching. We are already well on our way to defining such a knowledge base.

I envision the design of research-based programs of teacher education that grow to accommodate our conceptions of both process and content. These programs will articulate with and build upon instruction in the liberal arts and sciences as well as the specialty content areas of each candidate. Instructions in the liberal arts and content areas will have to improve dramatically to meet the standards of understanding required for teaching. If these are special sections of such courses for teachers, they will entail evaluation of subject-matter treatment, not watering down.

Such programs will draw upon the growing research on the pedagogical structure of student conceptions and misconceptions, on those features that make particular topics easy or difficult to learn. They will extensively employ a growing body of case literature, both to represent a far wider and more diverse range of teaching contexts than can possibly be experienced within any one teacher education program, and to provide teachers with a rich body of prototypes, precedents, and parables from which to reason.

The fact that we do not possess such a case literature at this time suggests new agendas for research in teacher education. In addition to the obvious tack of encouraging the continued growth of disciplined case studies of teaching by scholars, another alternative suggests itself. Fred Erickson has noted that one of the exciting features of case studies is that you don't necessarily have to be a PhD social scientist or educator to learn to prepare useful case materials. Given proper preparation and support, teachers and teacher educators can contribute to the case literature themselves. As they do so, they will begin to feel even more membership in the broader academic guild of professional teachers.

We reject Mr. Shaw and his calumny. With Aristotle we declare that the ultimate test of understanding rests on the ability to transform one's knowledge into teaching.

Those who can, do. Those who understand, teach.

Notes

[1]There is, in fact, a delightful ambiguity surrounding use of the word *methodology* in educational circles. It can refer to methods of teaching as well as methods of research. A person introduced as a specialist in methodology might these days be claiming competence in either. But before the days of Descartes, the concept of methodology was far more unitary. Methods of inquiry did not typically involve elaborate empirical procedures and concomitant statistical analysis. Indeed, scholars did something far more revolutionary as the heart of method. They thought about their problem and organized a coherent, logical analysis of its structure. This analysis not only served as the structure of inquiry, it also constituted the structure of pedagogy. The scholar's expositions and disputations reflected the applications of the same method.

[2]There is also pedagogical knowledge of teaching—as distinct from subject matter—which is also terribly important, but not the object of discussion in this paper. This is the knowledge of generic principles of classroom organization and management and the like that has quite appropriately been the focus of study in most recent research on teaching. I have no desire to diminish its importance. I am simply attempting to place needed emphasis on the hitherto ignored facets of content knowledge.

[3]Although in this paper I discuss aspects of content knowledge (including content-specific pedagogical knowledge and curricular knowledge) exclusively, a proper professional board examination would include other equally important sections as well. These would assess knowledge of general pedagogy, knowledge of learners and their backgrounds, principles of school organization, finance and management, and the historical, social, and cultural foundations of education among many more. Exams would also tap teaching performance and other capabilities unlikely to be adequately assessed using conventional paper-and-pencil instruments. Discussion of the character of a professional board for teachers and its desirability, however, is appropriate for another paper.

[4]I must also acknowledge some potential disadvantages of cases as sources of teacher knowledge. Kahneman, Slovic, and Tversky (1982) have pointed out the potentially misleading character of cases. They refer to the memorable quality of vivid cases as significant sources of bias in reasoning. Both availability and representativeness are characteristics of cases that make them readily retrieved from memory; they also bias the decisionmaker's estimates of the frequency of their occurrence. The important test of a case is its contrast with other cases and its examination in the light of principles. Such disciplined evaluation of cases can temper the inappropriate inferences that might be drawn from cases without diminishing their other virtues.

[5]It may well be that what I am calling strategic *knowledge* in this paper is not knowledge in the same sense as propositional and case knowledge. Strategic "knowing" or judgment may simply be a process of analysis, of comparing and contrasting principles, cases, and their implications for practice. Once such strategic processing has been employed, the results are either stored in terms of a new proposition (e.g., "Smiling before Christmas may be permissable when. . .") or a new case. These then enter the repertoire of cases and principles to be used like any others. In that sense, it is possible that strategic analysis occurs in the presence of the other forms of knowledge and is the primary means for testing, extending, and amending them.

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Teacher's knowledge

Having strong knowledge of mathematics does not guarantee that one will be an effective mathematics teacher, but teachers who do not have such knowledge are likely to be limited in their ability to help students develop relational and conceptual understanding.(Skemp 1976) .

Forms of knowledge and various kinds of understanding

Instrumental,relational,conceptual,procedural,implicit,explicit,elementary, advanced, algorithmic, formal, intuitive, visual, situated, knowing that, knowing how, knowing why, knowing to

Instrumental understanding /Procedural knowledge: A Sequence of actions that can be learned with or without meaning.	Relational understanding / Conceptual knowledge: It is the knowledge which is rich in relationships. The learning of a new concept or a relationship implies the addition of a node or link to the existing cognitive structure, thus making the whole more stable than before.
1) Rules without reasons 2) Easier to understand within its own context 3) Rewards are more immediate and apparent 4) Can obtain the right answer more quickly and reliably 5) Learning of an increasing no. of fixed plans by which pupils can find their way from particular starting points to required finishing points. These plans tell them what to do at each choice junction, but there is no awareness of the overall relationship between successive stages and the final goal and the learner is dependent on an outside guidance for learning each new plan.	1) Knowing what to do and why 2) More adaptable to newer tasks 3) Easier to remember 4) Capable of serving as a goal itself 5) Builds a conceptual structure from which its possessor can produce an unlimited number of plans for getting from any starting point to any finishing point within the schema.

Generally we teach mechanically the procedures in teaching particularly the following examples.

Example 1: Finding the square root of a number.

Example 2: Finding the logarithm of a number.

Knowledge needed for teaching

The content and discourse of mathematics, including mathematical concepts and procedures, and the connections among them; multiple representations of mathematical concepts and procedures; ways to reason mathematically; solve problems and communicate mathematics effectively at different levels of formality(NCTM 1991).

Knowledge of mathematical facts (notations, conventions), concepts, procedures, and the relationships among them; knowledge of the ways that mathematical ideas can be represented; and the knowledge of mathematics as a discipline—in particular, how mathematical knowledge is produced, the nature of discourse in mathematics, and the norms and standards of evidence that guide argument and proof, general strategies (procedures) which guide the choice of which skills to use or what knowledge to draw upon at each stage in the course of solving problem or carrying out investigation .

What a teacher has to do while teaching:

1) Keep in mind that understanding comes from by successive approximations (hypothetico- deductive) and requires considerable mental effort on the part of students. Give students the time and the challenge they need. Teachers must immerse learners in complex, interactive experiences that are both rich and real. i.e., pose questions and give tasks that elicit, engage and challenge each student's thinking.

2) Listen carefully to student's ideas. Keep asking and encourage students to ask, How do you know that (statement, fact, principle, prediction) is true? i.e., ask him to clarify and justify their ideas.

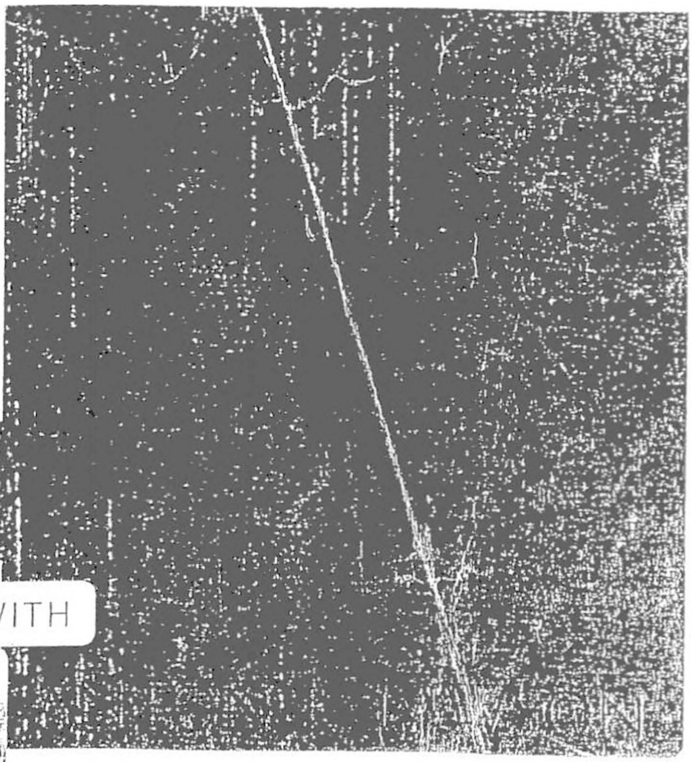
3)Decide what to pursue in depth from among the ideas that students bring up during a discussion and also decide when and how to attach a mathematical notation and language to student's ideas.

4) Assure students that making mistakes is a normal part of the learning process. "Fail to succeed. Intentionally get it wrong to inevitably get it even more right. Mistakes are great teachers—they highlight unforeseen opportunities and holes in your understanding. They also show you which way to turn next, and they ignite your imagination"(From the book of Five Elements of Effective Thinking).

5) Make students believe that logical mathematical reasoning is the authority within the class room rather than the status of the person sharing their thoughts by constant use of reasoning and proof.

(NCTM)

Finally, your teaching must be meaningful to be remembered, coherent to be understood, planned to be continuous, and enjoyed to be sustained for the rest of one's life.



AN INTERVIEW WITH

LIBERATO CARDELLINI

About Anton E. Lawson

Professor Lawson's career in biology education began in the late 1960s in California where he taught middle school science and mathematics for three years before completing his Ph.D. at the University of Oklahoma and moving to Purdue University in 1973. Lawson continued his research career at the Lawrence Hall of Science, University of California, Berkeley in 1974, and then moved to Arizona State University in 1977, where he currently conducts research and teaches courses in biology, biology teaching methods, and research methods. Lawson has published more than 200 articles and more than 20 books including *Science Teaching and the Development of Thinking* (Wadsworth: Belmont, CA, 1995), *Biology: A Critical Thinking Approach* (Addison Wesley: Menlo Park, CA, 1994), and *The Neurological Basis of Learning, Development and Discovery* (Kluwer: Dordrecht, The Netherlands, 2003). Lawson's most recent book is an introductory biology textbook called *Biology: An Inquiry Approach* (Kendall/Hunt: Dubuque, IA, 2004). Lawson is perhaps best known for his research articles in science education, which have three times been judged to be the most significant articles of the year by the National Association for Research in Science Teaching (NARST). He has also received NARST's career award for Distinguished Contributions to Science Education Research as well as the Outstanding Science Educator of the Year Award by the Association for the Education of Teachers in Science.

LIBERATO CARDELLINI is a Professor in the Department of Materials and Earth Sciences at the Marche Polytechnic University, 60131 Ancona, Italy; e-mail: liberow@univpm.it.

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Cardellini: *Why did you choose to become a teacher?*

Lawson: In a sense, teaching chose me. In 1968 while the Vietnam War was still raging, I was a biology graduate student at the University of Oregon. At about the time I finished my master's degree, my draft board stopped issuing deferments for graduate students, but continued deferments for teachers. So I took a job teaching science and mathematics at a middle school in the San Francisco Bay area. By the time the war ended and I could return to graduate school, I had become so fascinated by the complexities of teaching that I decided to conduct my doctoral research on students instead of snails.

Cardellini: *Who are your intellectual fathers and what did you learn from them?*

Lawson: My intellectual fathers were my father Chet Lawson, and Jack Renner and Bob Karplus. When I was about eight years old, I recall riding in the back seat of our car on a family trip to Pennsylvania. The sky was full of clouds, some brilliant white, others dark, almost black. So I asked my father why the clouds were different "colors." His reply was typical. "Good question, Tony—what ideas do you have?" I do not recall the rest of the conversation except to say I am certain that he did not tell me the right answer, which I am sure he knew. I suspect that growing up on a steady diet of these sorts of exchanges taught me to enjoy thinking about, and trying to explain, things. This lesson was reinforced several times by Jack Renner, my doctoral committee chair. Jack liked to say that giving students the right answers stops, rather than starts, thinking. During the 1970s, I had the good fortune of working with Bob Karplus at the Lawrence Hall of Science. I learned way too much from Bob to enumerate particulars except to say that it was a joy working with such a brilliant, energetic, and hard working person. For teachers who do not know of Bob's many contributions to science education, I strongly recommend reading *A Love of Discovery: Science Education–The Second Career of Robert Karplus* (Fuller, 2002), which contains a collection of his works.

Cardellini: *What components of Jean Piaget's theory are important for teachers?*

Lawson: Perhaps the first thing to understand about Piaget's theory is that he was talking about the acquisition of "how to" knowledge (procedural knowledge) and its importance in the acquisition of "know that" knowledge (declarative knowledge). For example, one needs to know *how to* count to *know that* there are ten marbles on the table. In biology, one needs to know *how to* sort, classify and seriate to *know that* species diversity increases from the poles to the equator. And one needs to know *how to* test theories to *know that* evolution has occurred as opposed to special creation.

According to Piaget's theory, the development of procedural knowledge occurs as a consequence of both physical and social experience, neurological maturation, and self-regulation. Self-regulation occurs when self-generated ideas and behaviors are contradicted. These contradictions lead not only to new ideas and new behaviors, but also to improved reasoning abilities. The evidence certainly supports this view. Perhaps the most important implication is that the really important aspects of science and mathematics literacy, such as effective reasoning and problem-solving abilities, cannot be directly taught. Instead, they are the products of intellectual development.

A serious educational problem stems in part from the fact that although people generally know if and when they learned a specific piece of declarative knowledge, they seldom know if and when their procedural knowledge developed. This means people who lack higher-order reasoning abilities do not realize their deficiencies, while people who have developed higher-order reasoning abilities assume incorrectly that everyone else has developed them as well! Not surprisingly a number of problems result, not the least is that many teachers, administrators, test developers, and policy makers ignore procedural knowledge and focus solely on teaching and testing declarative knowledge. I am afraid that because the pace of intellectual development lags in so many students, a huge portion of what we try to teach junior high and high school students (and even many college students) is missing the mark. Instead, it simply "goes in one ear and out the other." I certainly recall my own experience as a student taking high school biology. I learned next to nothing in spite of receiving a good grade. The good news is that once the problem is understood, there is a lot that teachers can do to help students develop their reasoning abilities and construct understanding of the really important scientific concepts and theories.

Cardellini: *In books and articles, you have demonstrated that some misconceptions are persistent (e.g., Lawson, Lewis & Birk, 1999). How can we deal with students' errors?*

Lawson: The article you cite provides a wonderful example. The phenomenon in question involves

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a lighted candle sitting in a pan of water. When an inverted glass is placed over the candle and into the water, the flame goes out and the water rushes up into the glass. Many students initially believe that the water rises because the flame "consumes" the oxygen trapped under the glass, so the water is "sucked" in to replace the now-empty space. This explanation contains two misconceptions. First, flames do not consume anything in the sense that matter is not destroyed. Instead, flames convert oxygen gas to carbon dioxide gas. Second, suction (as a pulling force) does not exist. Instead, the relatively greater air pressure outside the glass pushes the water up inside the glass.

Helping students understand the accepted scientific explanation for why the water rises, and to understand why the scientific explanation is accepted instead of the more intuitively-appealing explanation, is no small matter because acceptance requires not only understanding kinetic-molecular theory, but also knowing how to generate and test alternative hypotheses, in this case hypotheses involving unseen theoretical entities (i.e., atoms and molecules). Nevertheless, the best instructional approach encourages students to first explore the puzzling phenomenon, raise the causal questions, generate several possible explanations, and then attempt to test them experimentally. For example: If the water rises due to the consumption of oxygen, and we repeat the experiment varying the number of burning candles, then the water should continue to rise to the previous level (more burning candles will consume the available oxygen faster, but will not consume more oxygen). Alternatively, if the water rises because the air has been heated, has expanded, and some has escaped out the bottom, increasing the number of burning candles should cause water to rise higher (more burning candles will heat and drive out more air, thus further reducing the internal air pressure).

Biology teachers are often confronted by what we might call the "special creation" misconception, which for some students can be as persistent as the suction misconception. Dealing with the special creation misconception (or more recently the "intelligent design" misconception) can be even more difficult because its roots lie in an often emotionally-charged religious belief. For some students, accepting the scientific explanation for species diversity means rejecting part of their dominant and guiding religious worldview. Nevertheless, I believe the teacher's role is essentially the same as above, which is not to tell students what to believe, but to help them learn how to come to a belief. And in a science class this means that we again propose alternative explanations and then test them. Fortunately, with respect to the alternative theories of evolution and special creation there are several ways this can be done (e.g., Lawson, 1999; Lawson, 2004; Nelson, 2000). With respect to the fossil record, for example, several observations contradict special creation theory and support evolution theory, e.g.: If special creation theory is correct, and we compare fossils from the older/lower rock layers to those from younger/higher layers and to present-day species, then:

- Species that lived in the remote past (lower layers) should be similar to those living today;
- The older layers should be just as likely to contain fossils similar to present-day species as the younger layers;
- The simplest as well as the most complex organisms should be found in the oldest layers containing fossils, as well as in more recent layers; and
- A comparison of fossils from layer to layer should not show gradual changes in fossil forms, in other words, intermediate forms should not be found.

The key point in the classroom is that science teachers should be open to all ideas (even those they know to be wrong). However, the ideas, once generated, must be tested. Importantly, scientific beliefs are formed *after* consulting the evidence—not before. Students need to learn this, but don't when we simply tell them which ideas are right and which are wrong.

Cardellini: *You have studied instructional approaches to help students improve their reasoning abilities. What is the most effective approach?*

Lawson: I may have just answered this question. This is because reasoning abilities develop when they are used and they are certainly used when alternative ideas are generated, tested, and contradicted by the evidence. Contradictions force students to reflect not only on what they initially believed, but also on their reasons (and reasoning) for those beliefs. The point is that arguments about which ideas are right or wrong, and why they are right or wrong, provide the motivation for reflecting on and eventually abstracting the

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reasoning patterns, the forms of argumentation, that are used in learning.

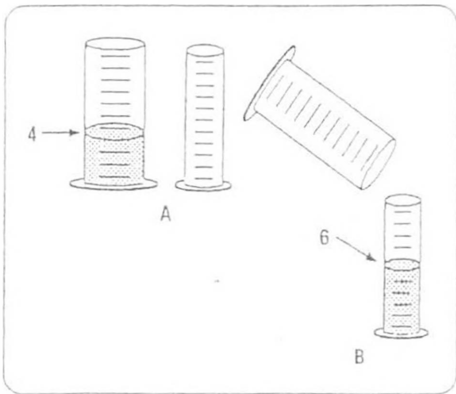
Cardellini: *How do people acquire knowledge and solve problems?*

Lawson: Importantly, there appears to be two ways to acquire knowledge and to solve problems. One way is through sheer repetition and/or via emotionally-charged contexts. Repetition and emotion can "burn" new input into long-term memory. Students can memorize biological terms, multiplication tables, and the positions of letters on a keyboard in this "rote" way. Unfortunately, memorizing scientific terms does not lead to understanding and to useful applications. Students can also learn to solve problems, such as those involving proportional relationships, in a rote way. For proportions this often includes use of a "cross-multiplication" algorithm:

e.g., 4/6 = 6/X, (4)(X) = (6)(6), (4)(X) = 36, X = 36/4, X = 9.

In spite of the fact that students can cross multiply and "solve" such problems, they typically have no idea why the algorithm works or how to solve "real" problems involving proportional relationships. For example, most middle and high school students can easily tell you that X = 9 in the previous equation, but when given the following problem, they incorrectly predict that water will rise to the 8th mark "... because it rose two more before, from 4 to 6, so it will rise 2 more again, from 6 to 8."

The Cylinders. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally-spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B). Both cylinders are emptied, and water is poured into the wide cylinder up to the 6th mark. How high will this water rise when poured into the empty narrow cylinder?



The same sorts of difficulties often emerge in biology classes when students are told to use Punnett squares to solve genetics problems. Many students lack the combinatorial and proportional reasoning abilities and/or the understanding of meiosis and Mendelian theory needed to know when and how to use Punnett squares. Thus, for them the application is rote and often confused and unsuccessful.

Fortunately, there is a second way to learn. That way is to link new ideas with prior ideas. This connectionist (or constructivist) way of learning has several advantages, not the least of which is that learning is not rote. Instead it connects to what one already knows, and thus becomes much more useful in reasoning and problem solving. In the case of proportions, this means that students not only know how to solve for X, they also know when to use a proportions strategy and when not to, i.e., they know when other strategies, such as addition and subtraction, should be used instead. The point is that if we want students to become good scientific thinkers and good problem solvers, we cannot teach in ways that lead to rote learning. Instead, we need to become connectionist teachers.

Cardellini: *What is the role of analogy in science education?*

Lawson: Analogy, or analogical reasoning, plays a huge role in science, and it should play a huge role in science education as well. In science, analogical reasoning is involved in the invention of hypotheses and theories. For example, in 1890 Elie Mechnikoff watched starfish larvae under his microscope, as he tossed a few rose thorns among them. To his surprise, he noticed that the larvae quickly surrounded and dissolved the thorns. This seemed to Mechnikoff to be analogous to what happens when a splinter gets stuck in a finger. Pus surrounds the splinter, which Mechnikoff hypothesized consists of tiny cells that attack and eat the splinter. So through the use of analogical reasoning, Mechnikoff "discovered" the bodies' main defense mechanism—namely mobile white blood cells that swarm around and engulf materials such as splinters and invading microbes.

Charles Darwin's invention of natural selection can also be traced to an analogy—in Darwin's case the analogy was between artificial selection of domestic plants and animals and the selection process that he imagined occurs in nature (i.e., natural selection). Other examples of analogical reasoning are numerous in history of science. Kepler borrowed the ellipse from Appolonios to describe planetary orbits. Mendel borrowed algebraic patterns to help explain hereditary patterns. Kekulè borrowed the image of a snake biting its tail (in a dream) to create a molecular structure for benzene. And Coulomb borrowed Newton's patterns of gravitational attraction to describe the electrical forces that exist between sub-atomic particles.

The classroom implication is that students need freedom to explore nature in the lab and field to discover puzzling observations. Students should then be encouraged to use analogical reasoning to creatively generate multiple explanations for the puzzling observations. To make sure that many ideas are freely generated, none should be criticized during this initial brainstorming period. But once several plausible explanations, and perhaps some not-so-plausible explanations, have been generated, they need to be tested. In this way, students learn new science concepts and theories in a way analogous to the way scientists initially invented them.

The key point is that most of the concepts that lie at the heart of modern scientific thought are theoretical in the sense that they are about non-perceptible entities and processes (e.g., atoms, DNA, photons, biogeochemical cycles, natural selection, protein synthesis). Thus for scientists to have invented the concepts and theories in the first place, they had to use analogical reasoning. Likewise, students must do the same. For example, for students to get some sense of what DNA is like, we can help by suggesting that it is like (i.e., analogous to) a twisted ladder. And to help them understand natural selection, we can have them participate in a simulation in which they play the role of birds capturing and eating mice (colored paper chips) in various habitats (pieces of colored fabric) (e.g., Stebbins & Allen, 1975; Maret & Rissing, 1998). Yet teachers need to keep in mind that although analogies and simulations should be sought and used as often as possible, their usefulness is limited by the students' ability to understand not only how the analogue and the theoretical target concept are similar, but also how they differ. After all, DNA is not really a twisted ladder!

Cardellini: *What are the greatest ideas that have been made available to teachers by educational research?*

Lawson: This will come as no surprise to experienced teachers, but the bottom line from educational research is that you cannot teach students much, if anything, of lasting value by talking to them. Effective teaching is *not* telling. Rather meaningful learning is a "constructive" process. Thus, the most effective approach to teaching is an "inquiry-based" approach based on the following four basic findings of educational research:

1. Learning is a natural process in which students are inherently curious and motivated to understand their world;
2. Students have distinctive experiences, interests, beliefs, emotional states, stages of development, talents, and goals that must be taken into account;
3. Learning occurs best when what is being learned is relevant and when students are actively engaged in creating new understandings and making new connections with prior knowledge; and
4. Learning occurs best in positive environments in which students' ideas and efforts are appreciated and respected (Lambert & McCombs, 1998).

All of this means that effective teaching takes teachers off center stage and puts student-generated questions, hypotheses, tests, evidence, arguments and conclusions on center stage. Interestingly, a classroom observational instrument has been recently developed called The Reformed Teaching Observation Protocol–RTOP for short. The RTOP contains 25 criteria for rating the extent to which classrooms are inquiry-oriented and "constructivist" in nature (e.g., students made predictions, estimations, and/or hypotheses and devised means for testing them; student exploration preceded formal presentation; students were reflective about their learning). Research has found very high positive correlations between RTOP scores and student achievement, particularly in the sciences (Adamson et al., 2003).

Cardellini: *What information as teachers do we need to know about neural theory in order to be more effective?*

Lawson: Your plumber needs to know how to stop leaks–not the molecular structure of water. Likewise teachers need to know how to help students develop intellectually and to learn–not how their neurons work. Nevertheless, it is important for teachers to know that what is being discovered about how brains work supports recent constructivist theory, which in turn supports an inquiry-based approach to teaching. Having said this, there are aspects of neural theory that are of interest. Perhaps the most interesting are:

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- Procedural knowledge patterns/rules reside in neural networks that are hierarchical in nature and culminate in single neurons located in the brain's prefrontal cortex (Wallis, Anderson & Miller, 2001);
- Declarative knowledge resides in associative memory, which is located primarily in the hippocampus, the limbic thalamus and the basal forebrain (Kosslyn & Keonig, 1995);
- Learning occurs when previously non-functional synapses become functional in one of two ways (Grossberg, 1982); and
- The brain is basically a hypothesis generating and testing "machine."

Let's consider the last two points in a bit more detail.

As mentioned when discussing knowledge acquisition and problem solving, there are two ways to learn. This is because there are two ways to produce functional synapses. One way is through sheer repetition and/or via emotionally-charged contexts. Repetition and emotion "burn" new input into one's synapses (one's long-term memory) essentially by boosting pre-synaptic activity to a high-enough level to create functional connections. Unfortunately, this rote way of memorizing information produces knowledge of very limited value because it remains disconnected to what one already knows. The second more effective way to form new functional synaptic connections involves linking new input with prior ideas. When neural activity is simultaneously boosted by new input and by prior ideas, the resulting pre- and post-synaptic activities combine to create new functional connections. This second way of learning produces useful transferable knowledge because the new knowledge is connected to what one already knows.

Another significant aspect of neural theory is that when the brain learns by linking new input with prior ideas, it does so in an *If/and/then* hypothetico-predictive way. Consider vision. Most people would guess that the brain processes information, including visual input, primarily in an inductive way—that is we look and we look again, and perhaps look still again, until we eventually induce an idea about what we are looking at. But this is not how the brain works (e.g., Kosslyn & Koenig, 1995). Instead, based on the initial look, the brain spontaneously and subconsciously generates a hypothesis of what might be out there and then uses subsequent looks to test its initial hypothesis. For example, suppose

Karen, who is extremely myopic, is rooting around the bathroom and spots the end of an object that appears to be a shampoo tube. In other words, the nature of the object's end and its location prompt Karen's brain to generate a shampoo-tube hypothesis. Based on this initial hypothesis, as well as knowledge of shampoo tubes stored in Karen's associative memory, when she looks at the other end of the object, she expects to find a cap: *If* it really is a shampoo tube (hypothesis), *and* I look at the other end (planned test), *then* I should see a cap (prediction). Thus Karen shifts her gaze to the other end (actual test). And upon seeing the expected cap (result), she decides that the object is in fact a shampoo tube (conclusion).

The point here is that because the brain learns best by generating and testing hypotheses, it follows that the most effective way to teach is by encouraging students to generate and test hypotheses. Of course, the hypotheses students generate and test in science classes are not of the visual sort just discussed. Instead they are primarily causal in nature. Nonetheless, the hypothetico-predictive learning pattern remains the same.

Cardellini: *What are the great ideas of science that every citizen should know?*

Lawson: Every citizen should know that science is a collective enterprise that seeks to explain nature based on the open generation and test of ideas. Although science does not lead to proof or disproof, its collectiveness and openness ensure that mistakes are corrected. Consequently, science leads to useful knowledge—in the sense that reliable predictions about future events can be made. With respect to specific knowledge, I will agree, in part, with Richard Feynman (1995) when he put it this way:

> *If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation ... it would be the atomic hypothesis (or atomic fact, or whatever you want to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.* (p. 4)

I say in part because in my view equally important as the atomic hypothesis/fact, is the evolution hypothesis/fact that all living things that we see around us today, and those that lived in the past, are descendants of simple bacteria-like creatures that came into existence some three to four billion years ago due to natural chemical processes that took place on a primitive Earth very unlike the one we live in today. When this idea of chemical and biological evolution is combined with the idea that the universe had its origin in a massive explosion some 12 to 15 billion years ago, with stellar evolution, with geological change, and with the idea that the universe today consists of countless galaxies, one begins to appreciate how unique each living thing is and how much there still is left to learn.

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Regional Institute of Education, Mysore RMSA Cell
Capacity building of State Resource persons by using In-service Teacher Professional Development package in Mathematics w.e.f. 12.3.2014 to 14.3.2014

PDay & Time	Session I 9.30 –11.00	11.00 - 11.15	Session II 11.15 – 1.00	1.00 – 2.00	Session III 2.00 – 3.30	3.30 – 3.45	Session IV 3.45 – 5.15
Wednesday 12.3.2014	Registration & Inauguration	T E A	Teaching of algebra Dr.B.S.Upadhyaya	L U	Cintinuous Professional Development DR.Y.Sreekanth (Combined Session)	T E A	Group Work on Algebra
Thursday 13.3.2014	Teaching of Geometry Dr.B.S.P.Raju	B R E	Group work on Geometry	N C	Inclusive Education Cr.C.G.Venkatesh Murthy &Dr. Somashekhar T.V.(Combined Session)	B R E	Understanding the adloscent learner- Pro.S.Ramaa (Combined session)
Friday 14.3.2014	Teaching of Statistics Dr. B.S.P.Raju	A K	Teaching of Number system Dr. Pradeep	H	Teaching of Mensuration Dr.Pradeep	A K	Presentation

Programme Coordinator PRINCIPAL

Regional Institute of Education, Mysore RMSA Cell
Capacity building of State Resource persons by using In-service Teacher Professional Development package in Science w.e.f. 12.3.2014 to 14.3.2014

Day & Time	Session I 9.30 –11.00	11.00 - 11.15	Session II 11.15 – 1.00	1.00 – 2.00	Session III 2.00 – 3.30	3.30 – 3.45	Session IV 3.45 – 5.15
Wednesday 12.3.2014	Registration and Inauguration	T E A	Photosynthesis Dr.V.V.Anand	L U	Continuous Professional Development Dr. Y.Sree Kanth (Combined Session)	T E A	Mole concepts &acids,Bases &salts Dr.Sreemathi
Thursday 13.3.2014	Periodic Table of elements Dr.Tamilselvan	B R E	Electicity &Magnitism Dr.Namboodri	N C	Inclusive Education Dr.C.G.Venkatesh Murthy,Dr.Somashekar, T.V.(Combined Session)	B R E	Understanding the adolescent learner Prof. S. Ramaa(Combined Session)
Friday 14.3.2014	Heridity and Evolution Dr.Imitiaz Beg	A K	Carbon &Its compounds Dr.Ravichandran	H	Light & Sound Dr Santosh Kumar	A K	Diversity in living organisms Dr. Geetha Nair & Dr. Tangpu. V.

Programme Coordinator

Appendix-I

<u>List of Resource Persons</u>

1.	Prof.B S P Raju	Prof. & Head DESM, RIEM	9986040628
2.	Prof.B S Upadhyaya	Prof. & Head DEE, RIEM	9448117280
3.	Prof.Y Sreekanth	Professor, NIE,NCERT	
4.	Prof.C G Venkateshmurthy	Professor in Education	9448959012
5.	Prof. S Ramaa	Professor in Education	9741314898
6.	Prof.C R Pradeep	Rtd.Professor,Dept.of Maths, IISc	9901357556
7.	Prof.V V Anand	Professor in Botany	9448869859
8.	Dr.T V Somasekhar	Assistant Professor	9611703249
9.	Dr.M S Srimathi	Associate Professor	9341292836
10.	Dr.Tamilselvan	Assistant Professor	9343322113
11.	Dr.Raman Namboodiri C K	Assistant Professor	8050490458
12.	Dr.Imtiaz Beg	Assistant Professor	9538245814
13.	Dr.Tangpu V	Assistant Professor	9035165158

APPENDIX -II

LIST OF PARTICIPANTS

Sl No.	Name , Designation, Address	Contact Number & E mail
1	Mr.Vineesh T V HSA (Natural Science) GHS Chenad, Chethalayam P.O S Bathery, Wayanad, Kerala	04936-238333/09745424546 hmgbschenad@gmail.com
2	Mr.Anil kumar M K HAS Mathematics SKMJ, HSS, Kalpetta P.O Wayanad Dist., Kerala	anilkumar.myladikandiyil@gmail.com
3.	Mr.Suresh Kumar K Physical Science, HAS A M HSS, Thirumok P.O Trivendrum- 695 006, Kerala	0471-2352171/9895993694 amhsstml@gmail.com
4	Mr.Sajikumar K G HAS, Govt V &HSS for Girls, Manacand, Tupm-11, Kerala	9495827275 Sajitupm11@gmail.com
5	Mr.P D Baby HAS (Physics), St Antonys HSs Poonjar, Poonjar South, P.O, Kerala	04822-275420 stantonysp@yahoo.in