Learning Science & The Nature of Science in Three-Part Harmony

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High Level Curricula in Science Education: Science Construction and Scientific Literacy

History of Thinking about NOS

Science is about *Hypotheses* testing and reasoning deductively from *Experiments*

(1900 to 1960)

Science is about *Theory* building and revision

(1960 to 1990)

Science is about *Model* building and revision

Models stand between Experiment and Theory

(1990 – present)

When did NOS become a focus of Science Education?

- James Bryant Conant (1947) *On Understanding Science: An Historical Approach* (Yale University Press)
- Science Education for Non-scientists – *lawyers, writers, teachers, public servants, businessman*
- Clarification of Popular Thinking about Methods of Science
- Close study of a FEW SIMPLE Case Histories
  - Cultural Assimilation of Science . . .in the New Age of machines and experts.
  - Some understanding of science – Pure & Applied (Is research & method different?) vs. Social Sciences (Is it really science?)

Tactics & Strategies of Science as the goal of science education for non-scientists (p 12)

- "The stumbling way in which even the ablest of the early scientists had to fight through thickets of enormous observation, misleading generalizations, inadequate formulations and unconscious prejudice is the story which it seem to me needs telling" (p 15)
- Philosophical analysis has led to misunderstandings of science (Logical positivism, language & logic
- "The case histories would almost all be chosen from early days in the evolution of the modern discipline." (p 17)
  - Physics – 17^{th} & 18^{th} Centuries
  - Chemistry – 18^{th} & 19^{th} Centuries
  - Geology – early 19^{th} Centuries
  - Biology – 18^{th} & 19^{th} Centuries (certain phases)

Explicit Teaching of NOS – Version 1

- Heuristic Principles & Consensus Views through Historical Cases and with Activities.
  - Taber, K. (2009) *Progressing Science Education: Constructing the Scientific Research Programme into the Contingent Nature of Learning Science*. Dordrecht: Springer
  - Niaz, M. (2009) *Critical appraisal of physical science as a human enterprise: Dynamics of scientific progress.* Milton Keynes, Springer.
  - McComus, W., Ed., (1998). *The nature of science in science education: rationales and strategies.* Dordrecht: Kluwer.
  - Lederman, N. & Lederman, J. (2004). "Revising instruction to teach nature of science: Modifying activities to enhance students' understanding of science". *The Science Teacher*, November.
  - (Mystery Tube, Bouncing Balls, Asteroids & Dinosaurs, Cube, . . .)

Explicit Teaching of NOS – Version 2

- Scientific Practices through Immersion Units & Learning Progressions
  - Duschl, R. (2000). Making the nature of science explicit. In R. Millar, J. Leech & J. Osborne (Eds.) *Improving Science Education: The contribution of research*. Philadelphia, PA USA: Open University Press.
  - Smith, C., Maclin, D., Houghton, C., & Hennessey, M.G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experience on epistemological development. *Cognition and Instruction, 18*(3), 285-316.
  - Lehrer, R., Schauble, L., & Lucas, D. (2008). Supporting development of the epistemology of inquiry. *Cognitive Development*, 23, 512-529.
  - Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95(3).*
  - (Whole Cases, Learning Progressions, Project/Problem Based Immersion Units)

3 Part Harmony Learning Goals

- Conceptual “guiding conceptions for what we need to know”
- Epistemic “rules for what counts as knowledge”
- Social “communicating & representing ideas, evidence and explanations”
- Duschl, R. (2008). Science education in 3 part harmony: Balancing conceptual, epistemic and social learning goals. *Review of Research in Education, V32*.

New Trends in Ed. Research: Designing Learning Environments

Richard A. Duschl
King’s College London

Viseu Portugal 2003

Learning How to Learn

- Advances in technology
- Advances in our basic understanding of:
  - Reasoning and scientific reasoning
  - The structure of knowledge and scientific knowledge
  - The Epistemic Processes associated with knowledge growth and development
- New Ways of ‘Seeing’ Classrooms

3 Ps

- **Psychology**
  - Cognitive Science, Information-processing, social psychology, activity theory
- **Philosophy**
  - Epistemology, History of Science; Sociology of Science; Argumentation
- **Pedagogy**
  - Inquiry Learning; Problem-based Learning; Community of Learners; Model-based Learning

Inquiry as a Mode of Learning
4 Goals

- Develop an understanding of the most important content.
- Develop understanding for doing inquiry and analyzing patterns.
- Develop reading skills and habits of mind for purposes of identifying and understanding knowledge claims.
- Develop the evaluative skills and habits of mind for assessing the status of knowledge claims. (Connelly & Finegold, 1977)

Teaching as Inquiry

- Identify the degree of legitimate doubt attached to science knowledge
- Assist in providing opportunities to deduce patterns and to develop intellectual capacity to inform oneself
- Employ a strategy of teaching that allows for discovery, focuses on the central role of discussion, and promotes effective argumentation.

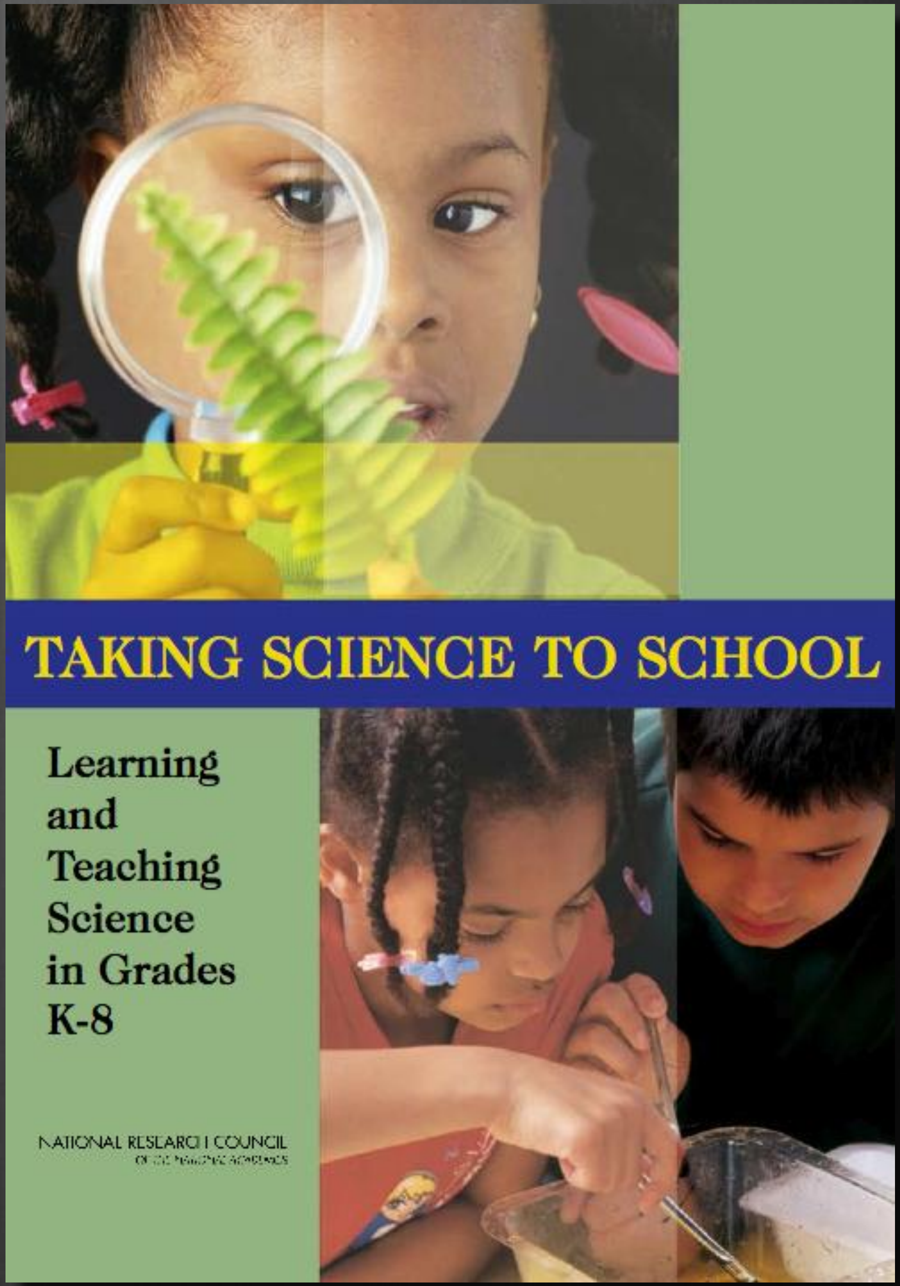
Inquiry Goal

- To assess the degree of legitimate doubt that can be attached to a knowledge claim (Connelly & Finegold, 1977)
- Such an assessment requires looking at:
  - Theoretical frameworks & commitments
  - Methodological frameworks & commitments
  - Goal & Aim frameworks & commitments

Taking Science to School (TSTS)

Ready, Set Science! (RSS)

National Research Council 2007



4 Strands of Science Proficiency

- Understanding Scientific Explanations – understand central concepts and use them to build and critique explanations.
- Generating Scientific Evidence – generating and evaluating evidence as part of building and refining models and explanations of the natural world.
- Reflecting on Scientific Knowledge – understand that doing science entails searching for core explanations and the connections between them.
- Participating Productively in Science – understand the norms for presenting scientific arguments and evidence and practice productive social interactions with peers around classroom science investigations.

NRC, 2008 Ready, Set, Science!

What Is Science?

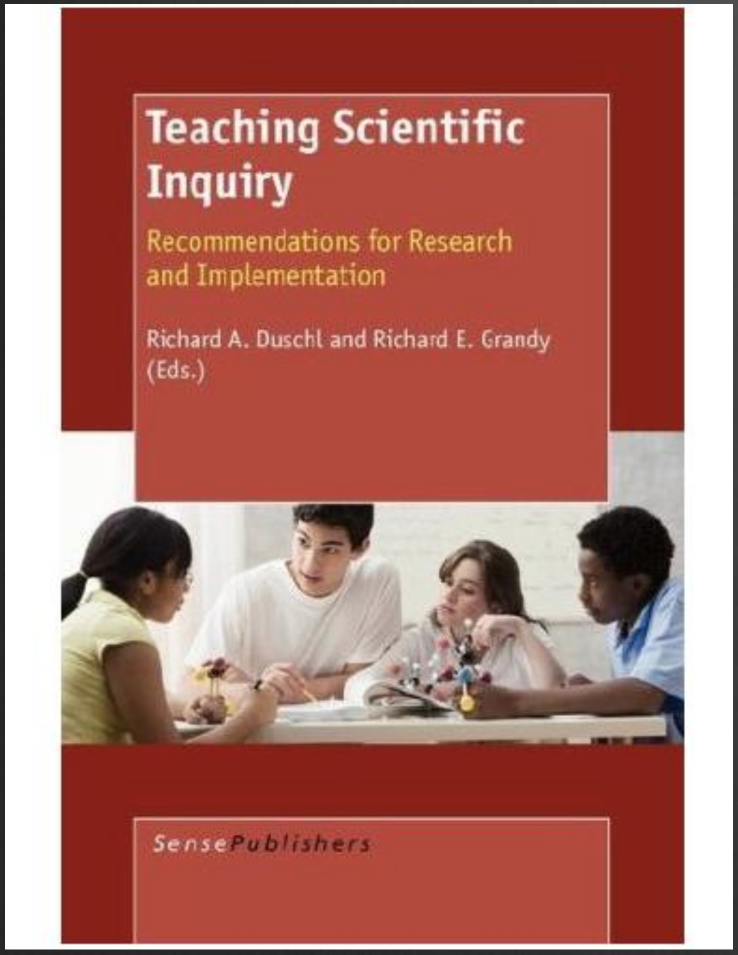
Science is built up of facts as a house is of stones, but a collection of facts is no more a science than a pile of stones is a house. -Henri Poincare

- Science involves:
  - Building/Refining theories and models
  - Collecting and analyzing data from observations or experiments
  - Constructing & Critiquing arguments
  - Using specialized ways of talking, writing and representing phenomena
- Science is a social phenomena with unique norms for participation in a community of peers.

NRC, 2007 Taking Science to School

Pedagogy - Teaching Scientific Inquiry

NSF Conference, February 2005



- Enhanced 'Scientific Method' - based on dialogical practices
- Extended Immersion Units of Instruction - conceptual, epistemic, social goals
- Teacher Professional Development Models

Essential Features of Classroom Inquiry

- Learners are engaged by **scientific questions**
- Learners give priority to **evidence**, to develop & evaluate explanation to address the questions
- Learners **formulate explanations**
- Learners **evaluate explanations** against alternative explanations
- Learners **communicate and justify** explanations.
  (National Research Council, 2000)

Enhanced Scientific Method

(Duschl & Grandy, 2008)

- Respond to criticism from others
- Formulate appropriate criticisms of others
- Engage in criticism of own explanations
- Reflect on alternative explanations and not have a unique resolution

What does this look like during instruction?

Exercise for a Healthy Heart

Agree/Disagree with the following statements and provide a reason

~It matters where you take a pulse

Wrist, neck, thigh

~It matters how long you take a resting pulse

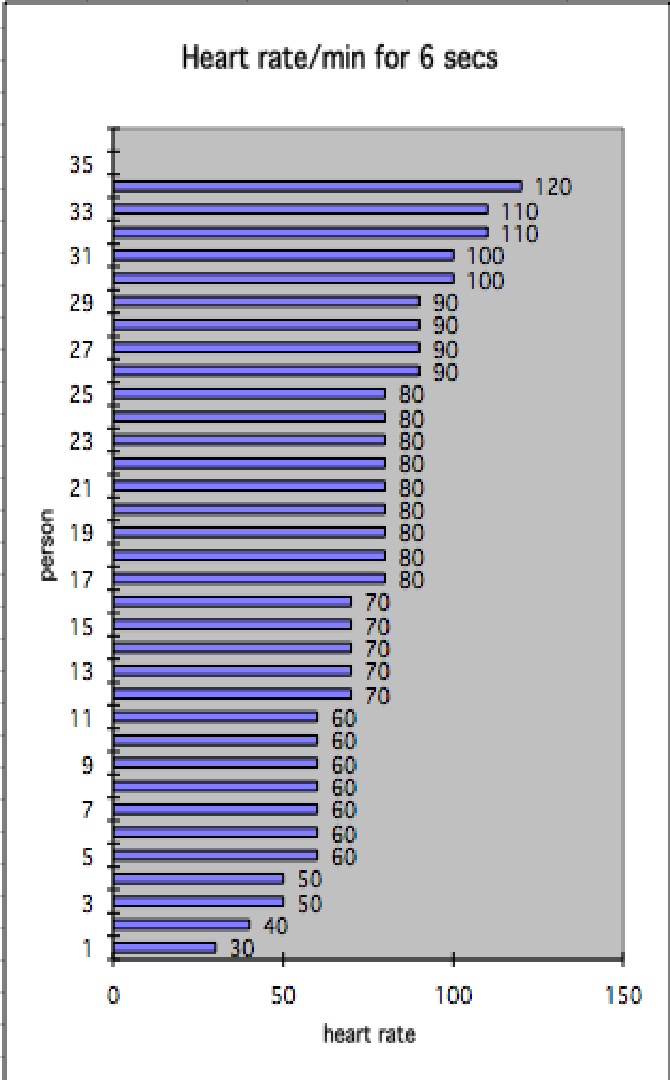
(6-10-15-60 seconds)

~It matters how long you take an exercising pulse (6-10-15-60 seconds)

~It matters who takes a pulse

Exercise for a Healthy Heart

- Agree/Disagree with the following statements and provide a reason
  - It matters where you take a pulse
    - Wrist, neck, thigh
  - It matters how long you take a resting pulse
    - 6-10-15-60 seconds
  - It matters how long you take an exercising pulse
    - 6-10-15-60 seconds
  - It matters who takes a pulse



Heart rate/min for 6 secs
person
heart rate
0
50
100
150
35
33
31
29
27
25
23
21
19
17
15
13
11
9
7
5
3
1
120
110
110
100
100
90
90
90
90
80
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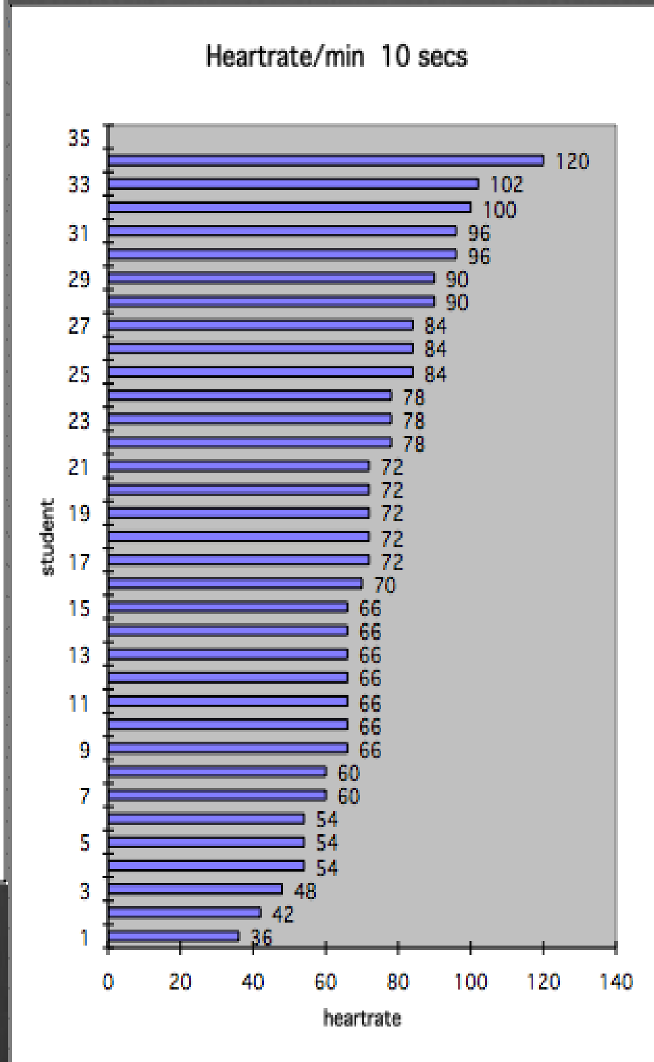
40
30



Heartrate/min 10 secs
student
heartrate
0
20
40
60
80
100
120
140
35
33
31
29
27
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23
21
19
17
15
13
11
9
7
5
3
1
120
102
100
96
96
90
90
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84
84
78
78
78
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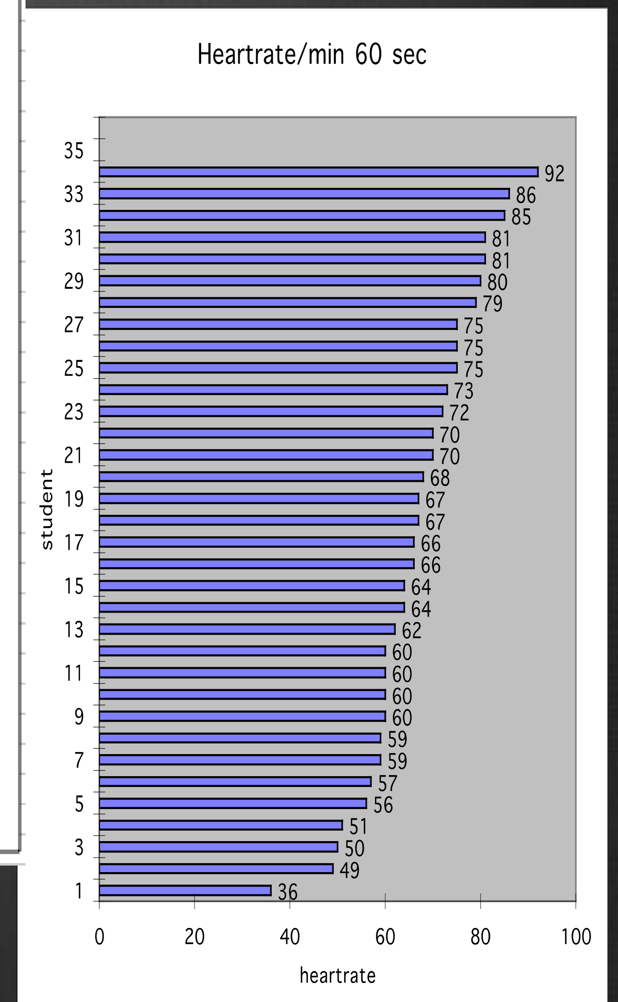

Heartrate/min 60 sec
student
heartrate
0
20
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60
80
100
35
33
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21
19
17
15
13
11
9
7
5
3
1
92
86
85
81
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79
75
75
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72
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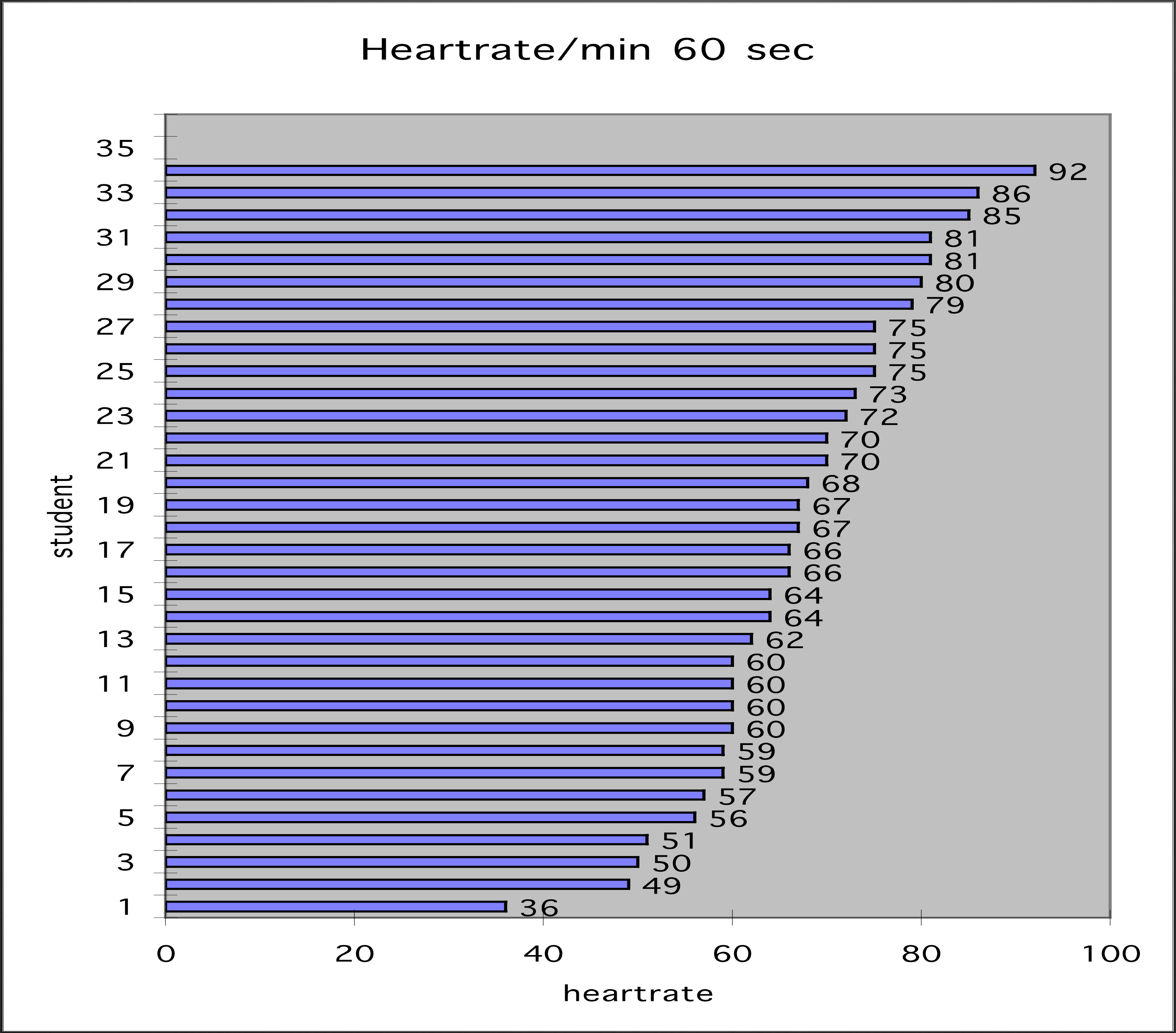

Heartrate/min 60 sec
student
heartrate
35
33
31
29
27
25
23
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19
17
15
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7
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3
1
0
20
40
60
80
100
92
86
85
81
81
80
79
75
75
75
73
72
70
70
68
67
67
66
66
64
64
62
60
60
60
60
59
59
57
56
51
50
49
36

Looking at the graphs, what do you think is the range for a healthy heart beat?

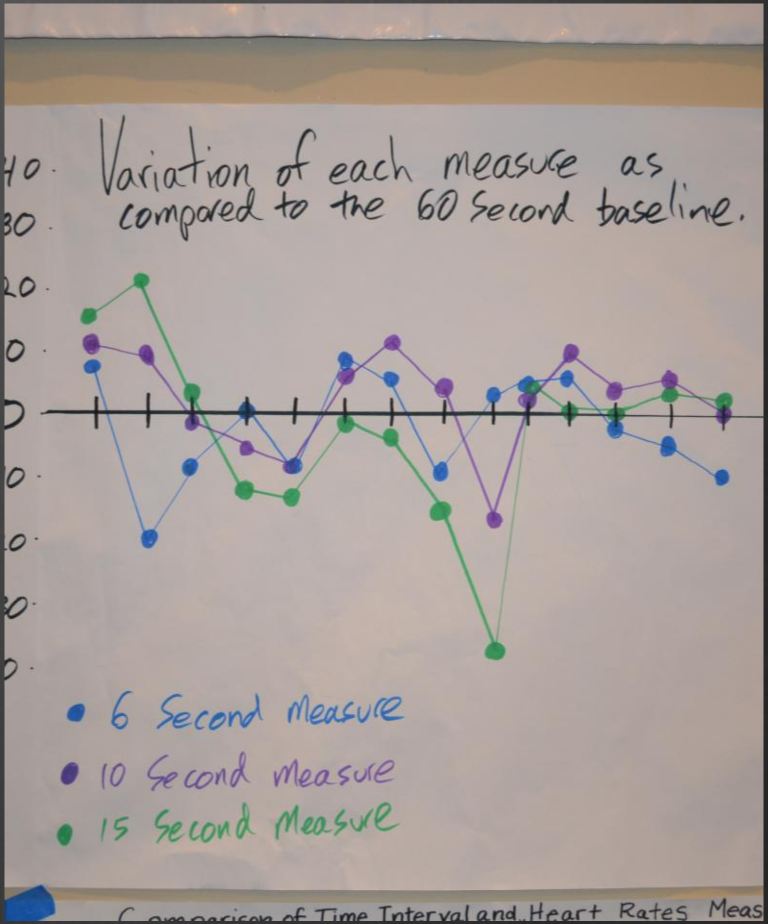
Group	Salient Characteristics of Lab Group Reasoning
1	Group 1 uses a ‘frequency’ decision rule to arrive at range of 60-80. That is, any heart beat with < 3 data entries was eliminated from calculations to determine the upper boundary for each graph; e,g, 90 for 6 secs., 104 for 15 secs., 72 for 10 secs., 75 for 60 secs. These 4 averages were then averaged to get 80 as the upper limit. All charts should be since to get an average all data should be used. Lab book shows that the decision rule changed with the consideration of each of the heart rate graphs.
2	Group 2 uses a ‘majority’ decision rule to arrive at a range of 60-80. That is, most of the data fell between 60 and 80. The 6 sec. chart should be used. Lab books shows that the decision rules remains the same for each of the heart rate graphs.
3	Group 3 used an ‘average’ decision rule based on how the data from the 4 members of their lab group, and not the class data, could be used to get the average and then establish the range. This strategy resulted in 4 separate ranges being reported for each of the 4 heart rate graphs. The selected range was 60-75. Final decision was based on 10 and 60 second graphs. Lab books show that the decision strategy is common across heart rate graphs but that the range results are different.
4	Group 4 used an ‘end points’ decision rule based on the end points of the normal range determined for each graph. Thus, a range of 70-80 for 6 sec., 66-72 for 10 sec., 60-80 for 15 sec., and 60-75 for 60 sec. 60 appears twice as the lower boundary and 80 appears twice as the upper boundary, hence the normal range is 60-80. All graphs used.
5	Group 5 used a ‘calculation’ decision rule to arrive at a range of 60-80. That is, each graph was analyzed to find out where 2/3 of the students’ heart rates fell on the graph. The 60 second graph was selected as the most accurate.

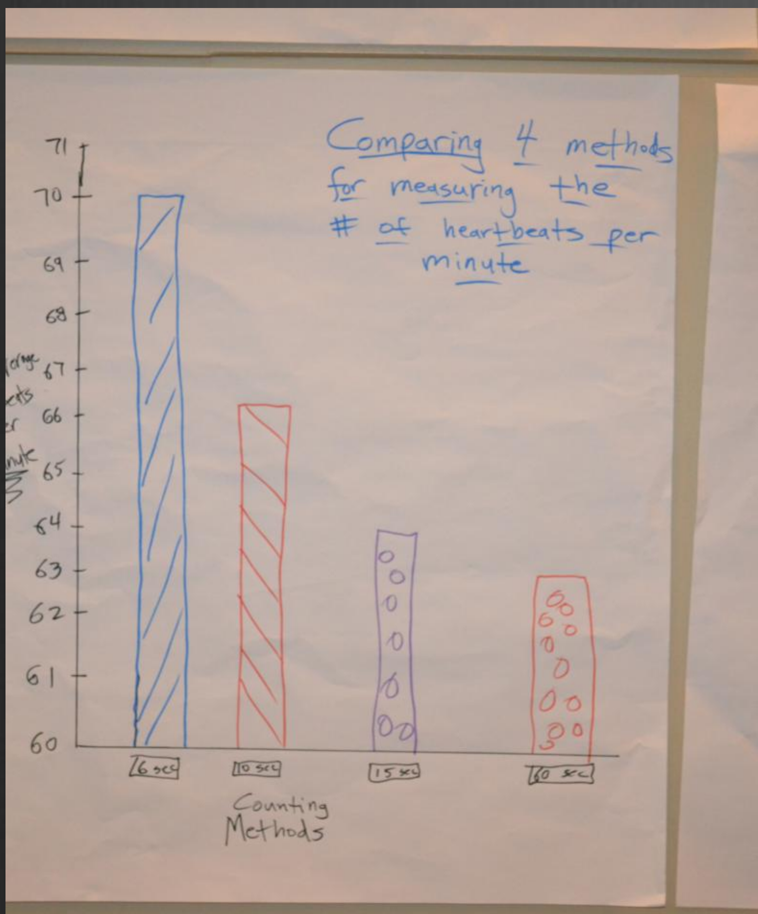
Group Decision Rules

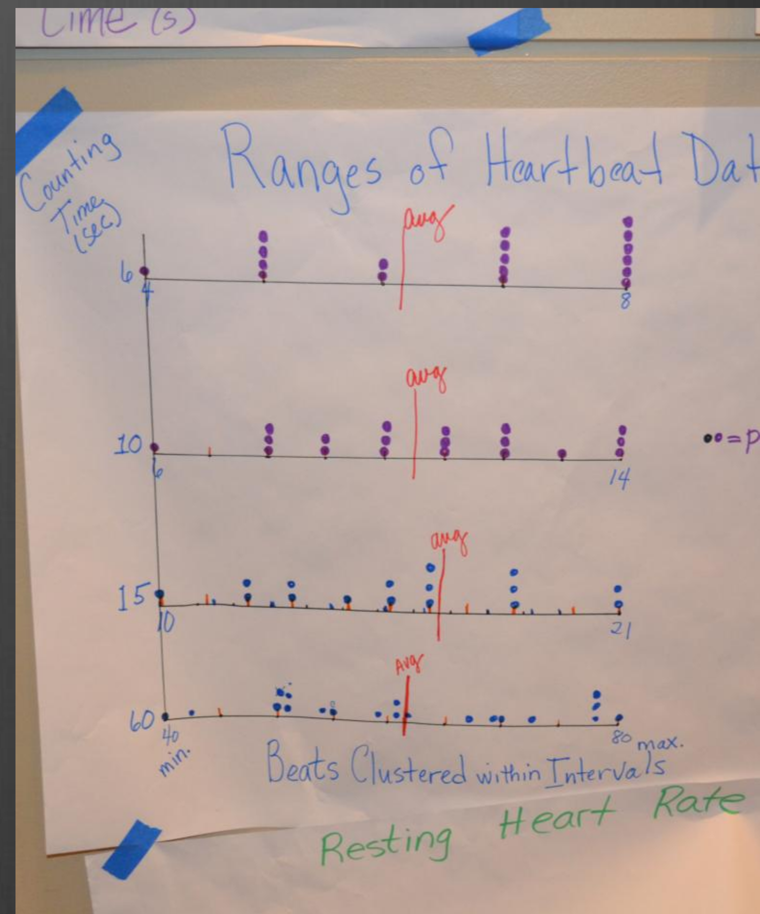
1 - Frequency
2 - Majority
3 - Average
4 - Endpoints
5 - Calculation

Teachers Doing the Same EHH Investigation

Teacher's Representations




Comparing 4 methods
for measuring the
# of heartbeats per
minute
71
70
69
68
67
66
65
64
63
62
61
60
6 sec
10 sec
15 sec
60 sec
Counting
Methods


Ranges of Heartbeat Dat
Counting
Time
(sec)
avg
6
4
8
avg
10
6
14
avg
15
10
21
Avg
60
40
min.
80
max.
Beats Clustered within Intervals
Resting Heart Rate

Learning to Reason about Variability and Chance by Inventing Measures and Models K-8

Richard Lehrer & Cliff Konold

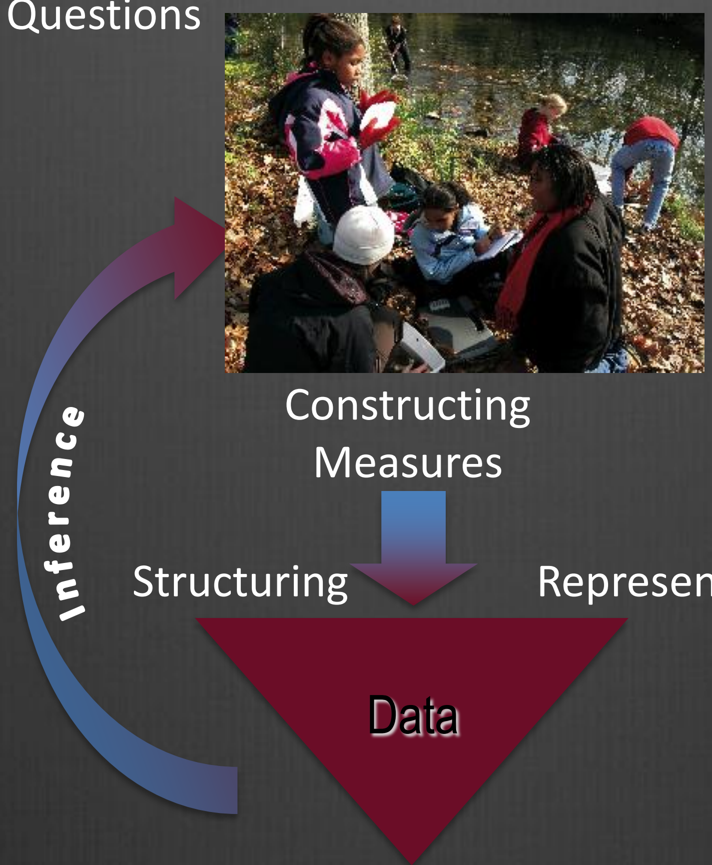
with

Min-joung Kim & Marta Kobiela,

Seth Jones & Eve Manz

NARST Presidential Symposium 2010

Data Modeling

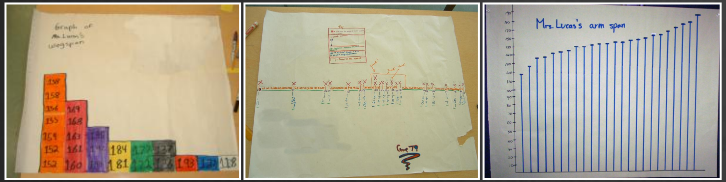


Repeated Measure

Repeated Measure Links Process to Data

Students all measure the same object, with different tools (e.g., a meter stick, a 15 cm. ruler.)

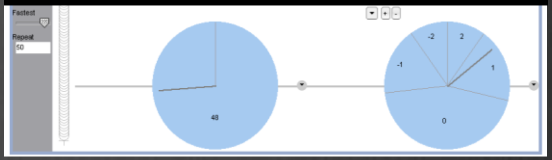
Inventing & Comparing Displays Develops Representational Competencies



Students consider how the shape of the data arises from the choices that designers make, such as count, order, and interval.

Modeling the Measurement Process Coordinates Chance with Pattern

Observed Measure =
Best Guess + Error



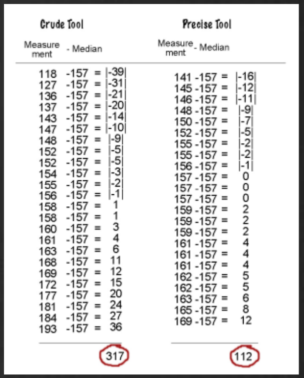
- What kinds of errors did we make?
- Is this a good model for the real measurements?

Explore

Chance

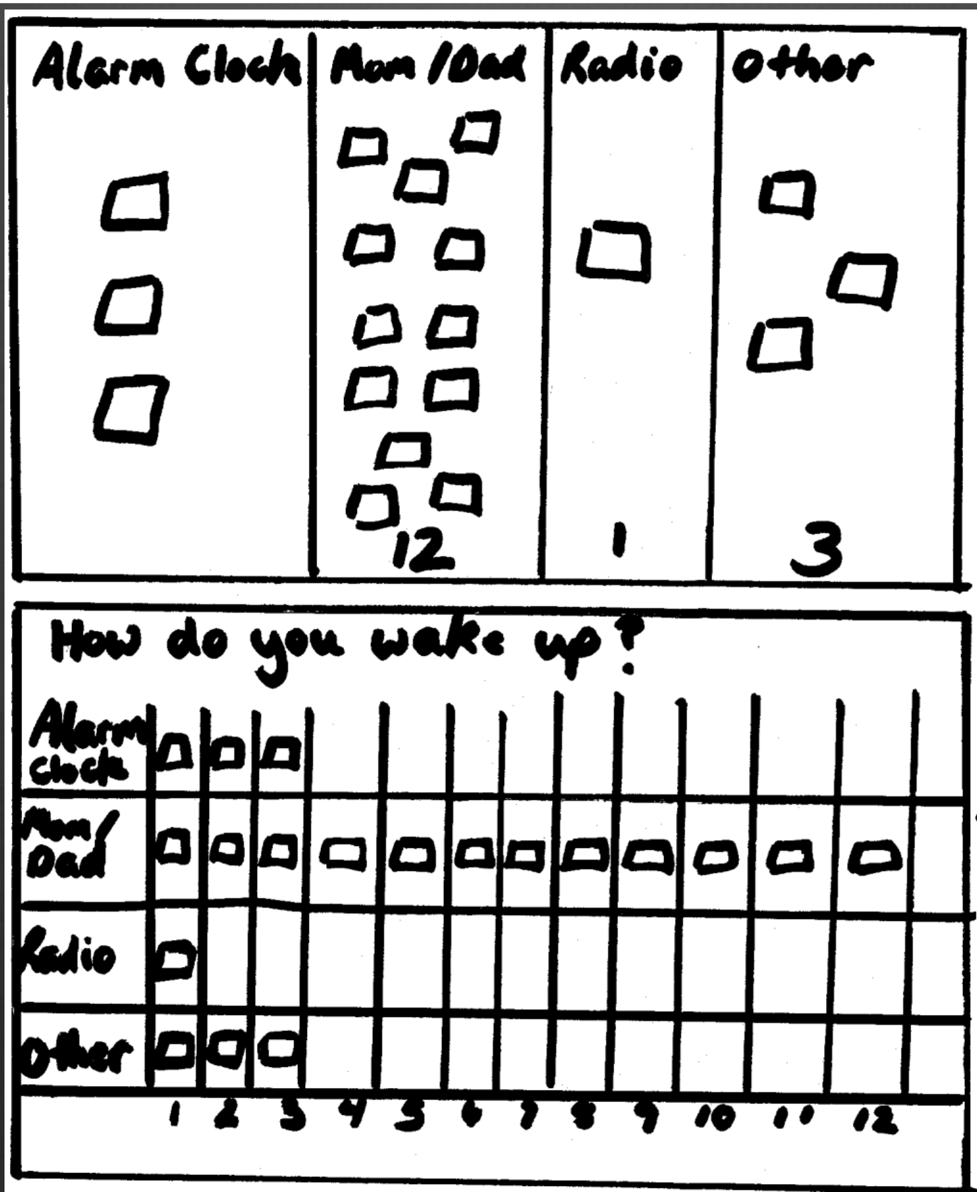
Inventing Statistics Clarifies How Statistics Measure Qualities of Distribution

- What is the real length of the teacher's arm-span?
- What was the precision of the measurement?

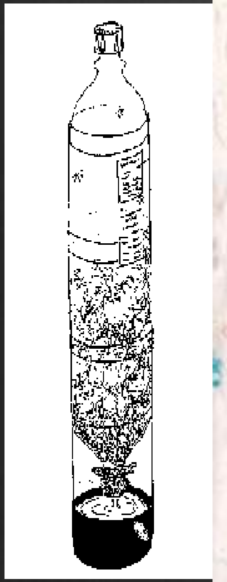


Crude Tool Measurement	- Median	=	Precise Tool Measurement	- Median	=
118	-157	$\lvert -39 \rvert$	141	-157	$\lvert -16 \rvert$
127	-157	$\lvert -31 \rvert$	145	-157	$\lvert -12 \rvert$
136	-157	$\lvert -21 \rvert$	146	-157	$\lvert -11 \rvert$
137	-157	$\lvert -20 \rvert$	148	-157	$\lvert -9 \rvert$
143	-157	$\lvert -14 \rvert$	150	-157	$\lvert -7 \rvert$
147	-157	$\lvert -10 \rvert$	152	-157	$\lvert -5 \rvert$
148	-157	$\lvert -9 \rvert$	155	-157	$\lvert -2 \rvert$
152	-157	$\lvert -5 \rvert$	155	-157	$\lvert -2 \rvert$
152	-157	$\lvert -5 \rvert$	156	-157	$\lvert -1 \rvert$
154	-157	$\lvert -3 \rvert$	157	-157	0
155	-157	$\lvert -2 \rvert$	157	-157	0
156	-157	$\lvert -1 \rvert$	157	-157	0
158	-157	1	159	-157	2
158	-157	1	159	-157	2
160	-157	3	159	-157	2
161	-157	4	161	-157	4
163	-157	6	161	-157	4
168	-157	11	161	-157	4
169	-157	12	162	-157	5
172	-157	15	162	-157	5
177	-157	20	163	-157	6
181	-157	24	165	-157	8
184	-157	27	169	-157	12
193	-157	36			
		317			112

Structuring Waking Up

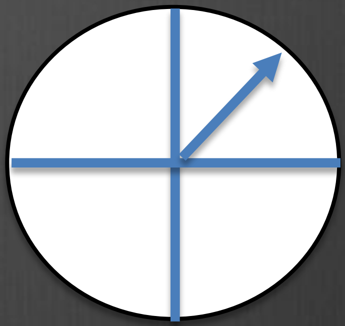


Fruit Fly Escape (G1)



Display-based Reasoning

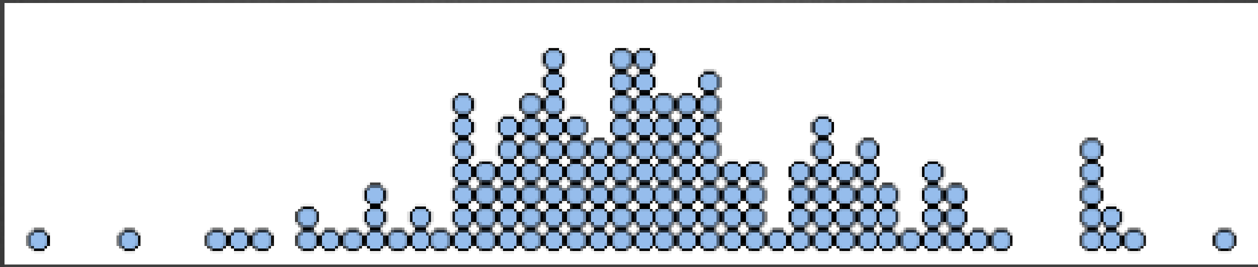
Linking Modeling with Chance



Model
- Exemplification
- Define Conditions
- Preference of crayfish

Chance (Model)
- Repeated process
- Trial?
- Sample?

Contexts for Statistical Investigation

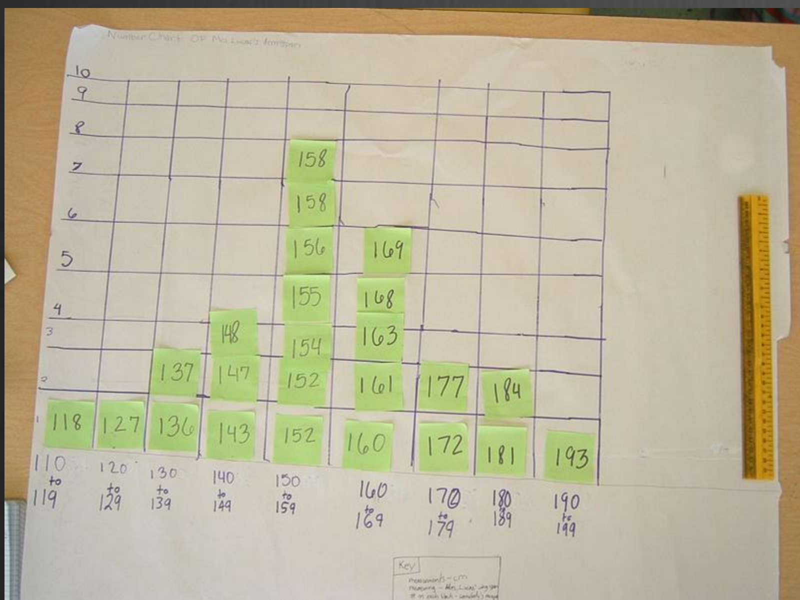


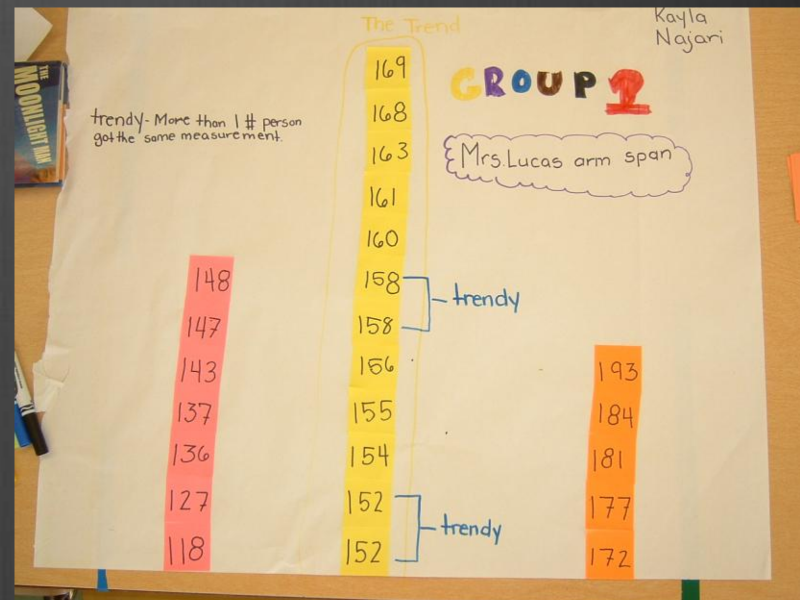
1. Repeated measures – head size
2. Manufactured objects – bolt diameters
3. Natural objects - height

Comparison of Context Properties

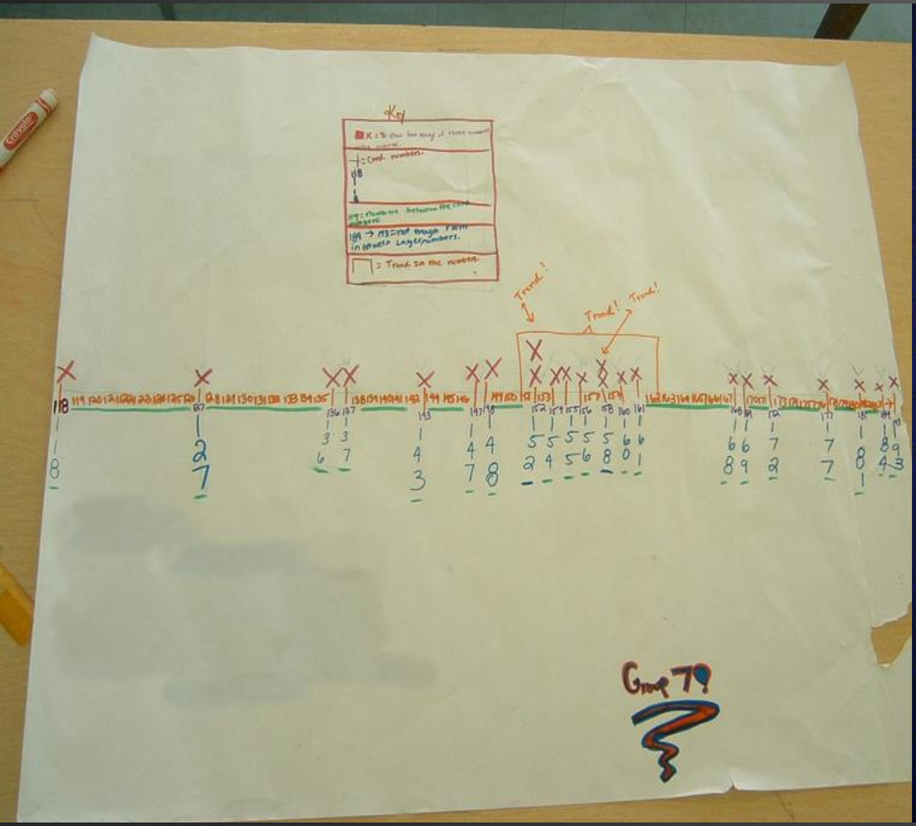
Context	Origin	Noise	Signal
repeated measures	observable measurement process	measurement error	true value
manufactured objects	observable mechanical process	process variation	target
natural objects	unobservable multi-system processes	individual differences	?

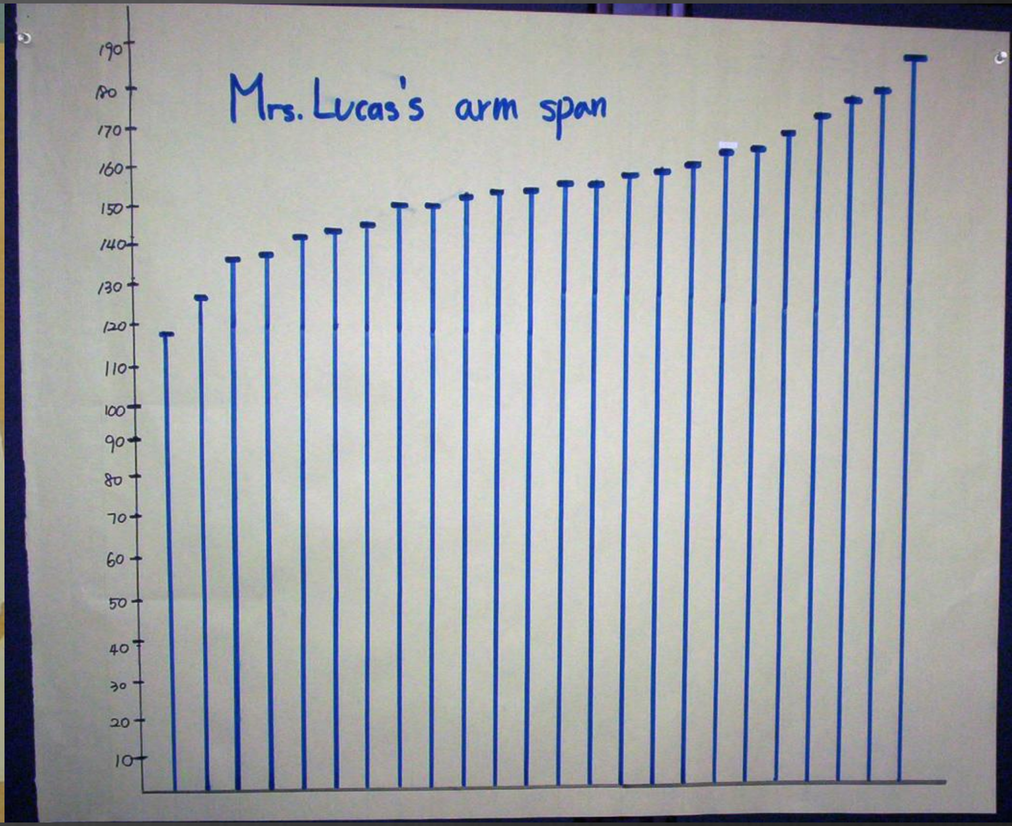
Order, Frequency, Group & Interval





Developing Meta-Representational Competence





Show and Hide

Modeling Measurements: ANOVA

- Epistemic Challenges
  - Models are analogies, but for many, models are copies.
  - Models of chance rely on a syntax of relations, do not instantiate relations literally. (Depart from exemplification)
  - Model fit

- Measurement = Best guess (True Measure) + Error
  - Challenges
    - Where does spread come from?
    - Can mistakes be random?

Modeling Errors

- **Error Analysis**
  - Identify sources
    - Wingspan data
      - Gaps and overlaps error
      - Teacher arm droop error
      - Ruler reading error
  - Conduct experiments about magnitudes of contribution (over and under)
  - Assign likelihoods to magnitudes
  - Design spinner model of each source of error
- **Run Model & Compare to Observations**
- **Create Bad Models**

"Setting up a model of the world to study the world does not come easy to children"
Leona Schauble, Vanderbilt University

- Prolonged experience with phenomena.
- Posing and revising questions – working over time to make explicit and refine criteria for good questions.
- Parsing objects and events into attributes that bear on the question.
- Considering/debating means of measuring attributes in ways that support an initial model of the phenomenon (considering the measure properties of those attributes.
- Generating/creating data (observing its measure qualities, reliability, etc.

Continued . . . . .

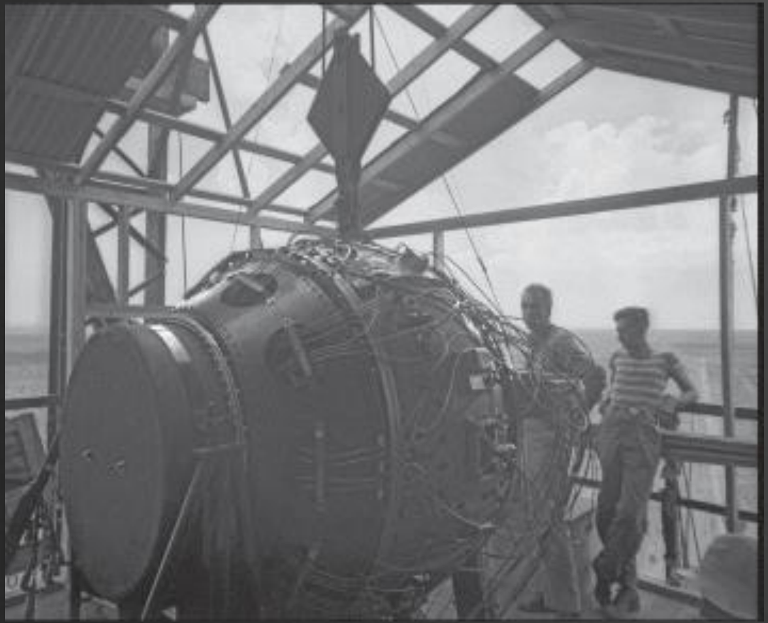
- Structuring data (patterns are made, not found)
- Interpreting data as evidence – model construction.
- Model testing against the original phenomenon & new cases
- Generation/entertainment of alternative models
- Evaluation of model fit
- Model selection/revision . . . . . .Which usually results in theoretically deeper questions.

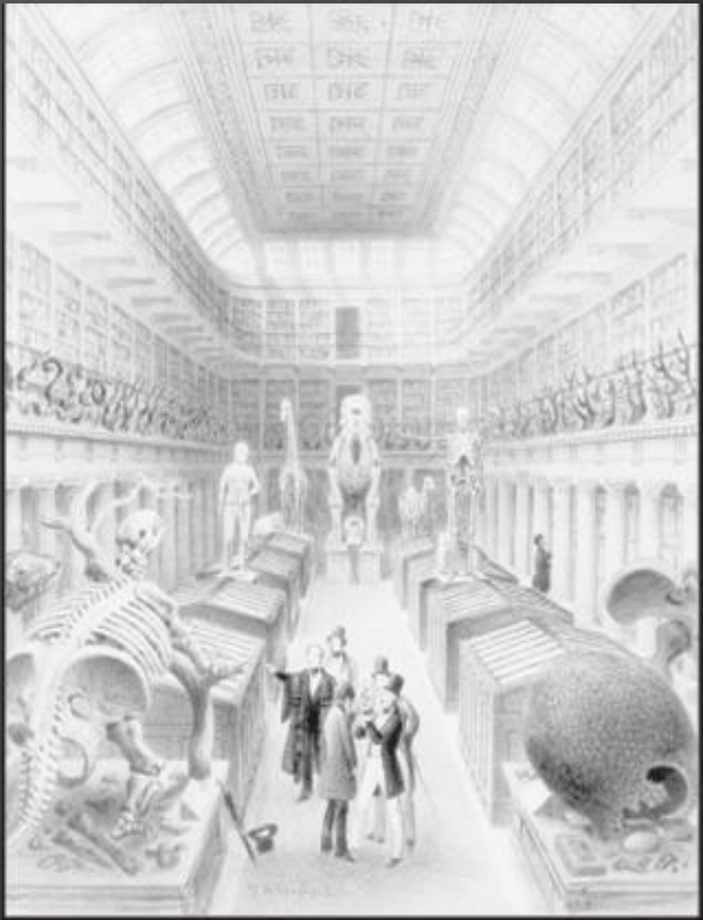
- Lehrer, R., Schauble, L., & Lucas, D. (2008). Supporting development of the epistemology of inquiry. *Cognitive Development*, 23, 512-529.

Explicitly Teaching NOS

- Attaching NOS labels and features to practical work and inquiry activities - Version 1
- Or
- Engaging in extended building and refining knowledge activities that involve problematizing measurement and observational data and evidence in the construction of models – Version 2

Philosophy & The Naturalistic Turn





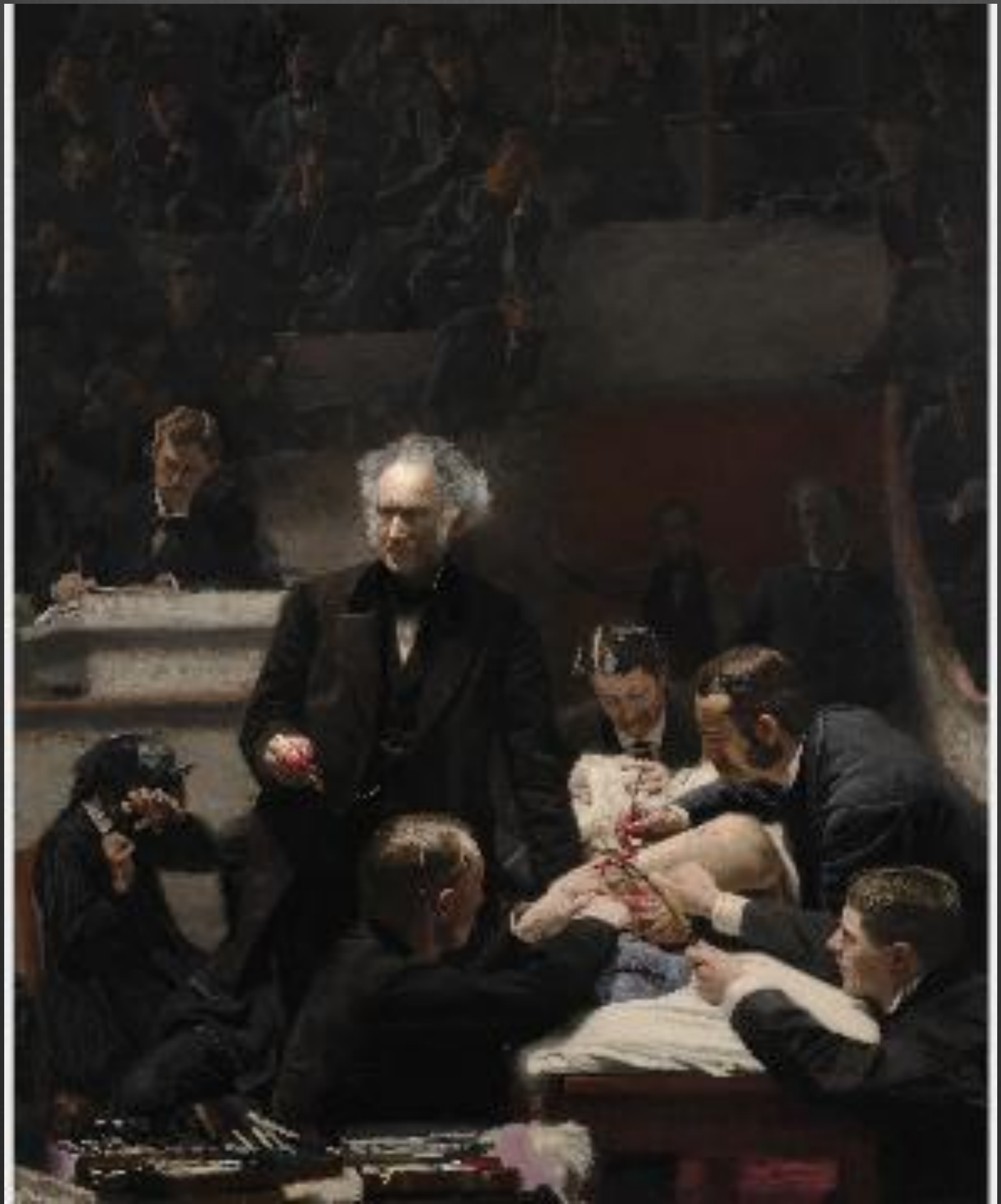
Transitional Steps to Naturalized Philosophy of Sciences

- Emergence of the Social Pragmatic View of Language via accounts of the ‘Causal Theory of Reference’ and the failure of formal inductive syntactical structures (heuristic principles) to explain explanations.
- Emergence of Cognitive Psychologies as the dominance of Behaviorism recedes leading first to Sense Data and second to Theory of Mind
- Emergence of Philosophy of Biology to introduce evolutionary ideas about emergence and the treatment of anomalous data.
- Emergence of History of Science and the subsequent shift from accounts of older history to accounts of newer or contemporary history to establish growth of knowledge mechanisms.
- Emergence of ‘Practices’ and Epistemic Cultures – cognitive and social – as a basis interpreting the building and refining of scientific knowledge and methods.
- Complex Systems and NOS

Deepening & Broadening Scientific Explanations (Thagard, 2007)

- **Epistemic Achievements**
- Relativity Theory
- Quantum Theory
- Atomic Theory of Matter
- Evolution by Natural Selection
- Genetics
- Germ Theory of Disease
- Plate Tectonic Theory

- **Epistemic Attempts**
- Crystalline Spheres Astronomy
- Catastrophist (Flood) Geology
- Phlogiston Theory of Chemistry
- Caloric Theory of Heat
- Vital Force Theory of Physiology
- Ether Theories of Electromagnetism and Optics
- Theories of Spontaneous Generation



Thomas
 Eakin

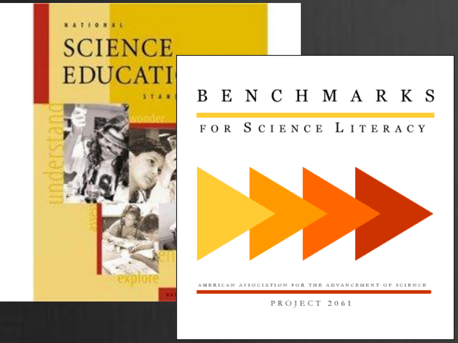
"The Gross
Clinic"

1875

New View of NOS

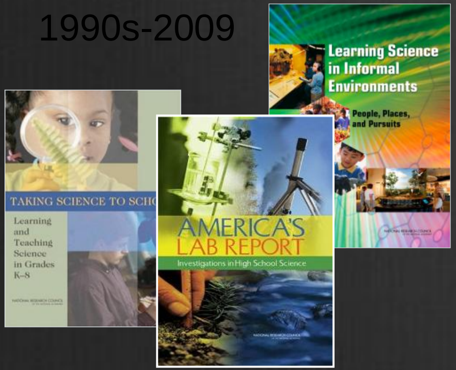
- Emphasizes the role of models and data construction in the scientific practices of theory development.
- Sees the scientific community, and not individual scientists, as an essential part of the scientific process.
- Sees the cognitive scientific processes and scientific practices as a distributed system that includes instruments, forms of representation, and agreed upon systems for communication and argument.

Building on the Past; Preparing for the Future

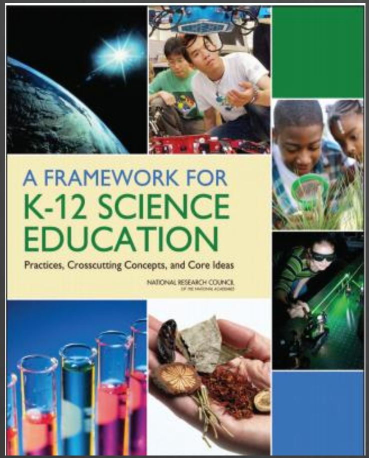


1990s

1990s-2009



Phase I



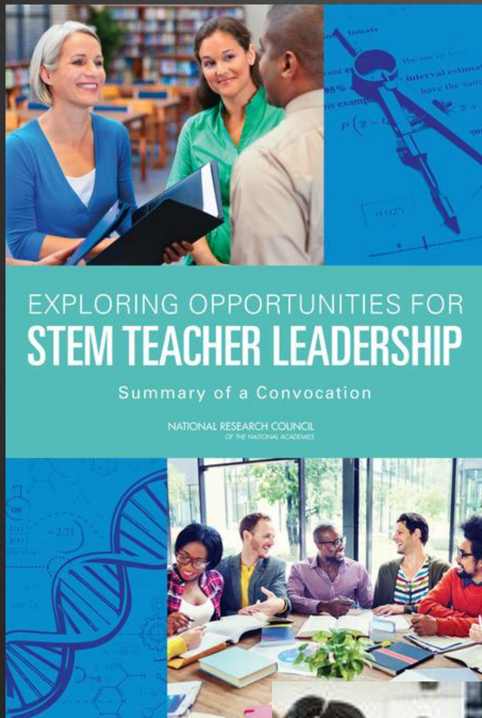
1/2010 - 7/2011

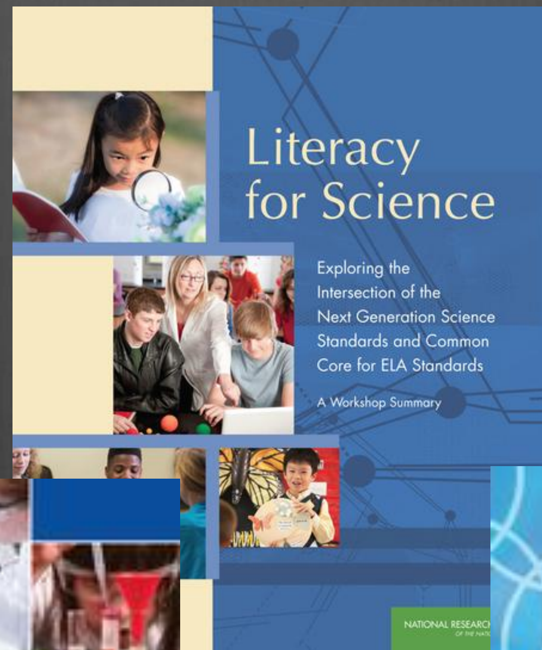
Phase II

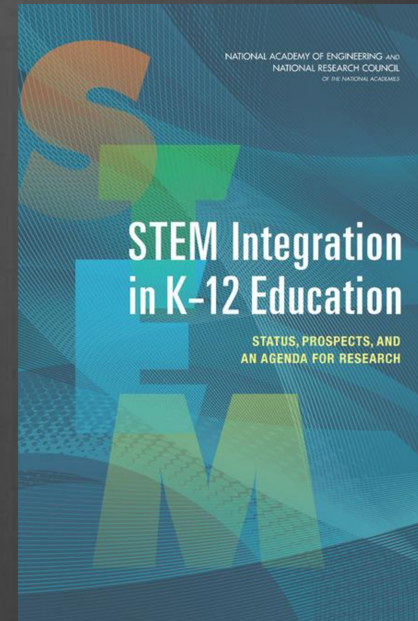
NEXT GENERATION SCIENCE STANDARDS
For States, By States

7/2011 – March 2013

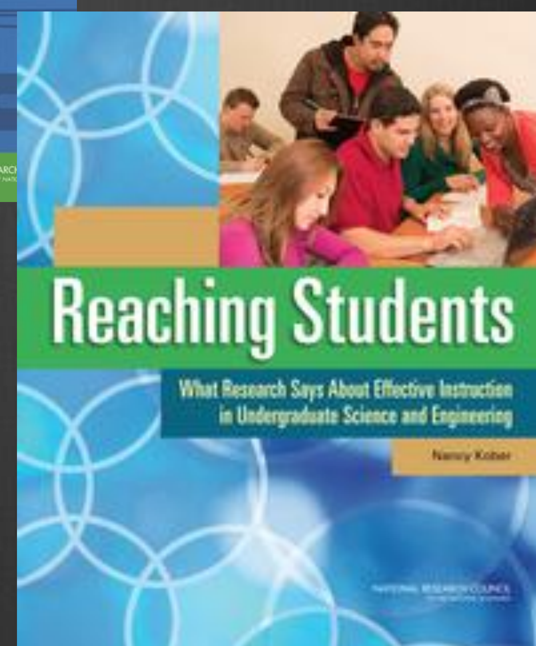
Innovations & Change
Who are the partners,
players?







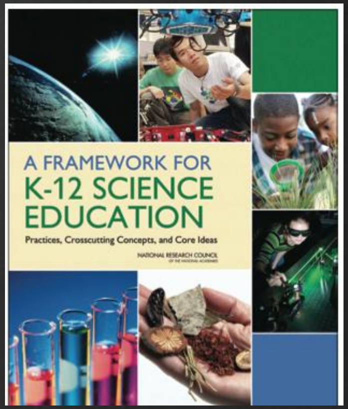
Going to
Scale



Framework 3 Dimensions

- Practices
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

- Crosscutting Concepts
- Patterns
- Cause & Effect
- Scale, Proportion & Quantity
- Systems and Systems Models
- Energy and Matter in Systems
- Form & Function
- Stability



- Core Ideas
  - Physical Sciences
  - Life Sciences
  - Earth/Space Sciences

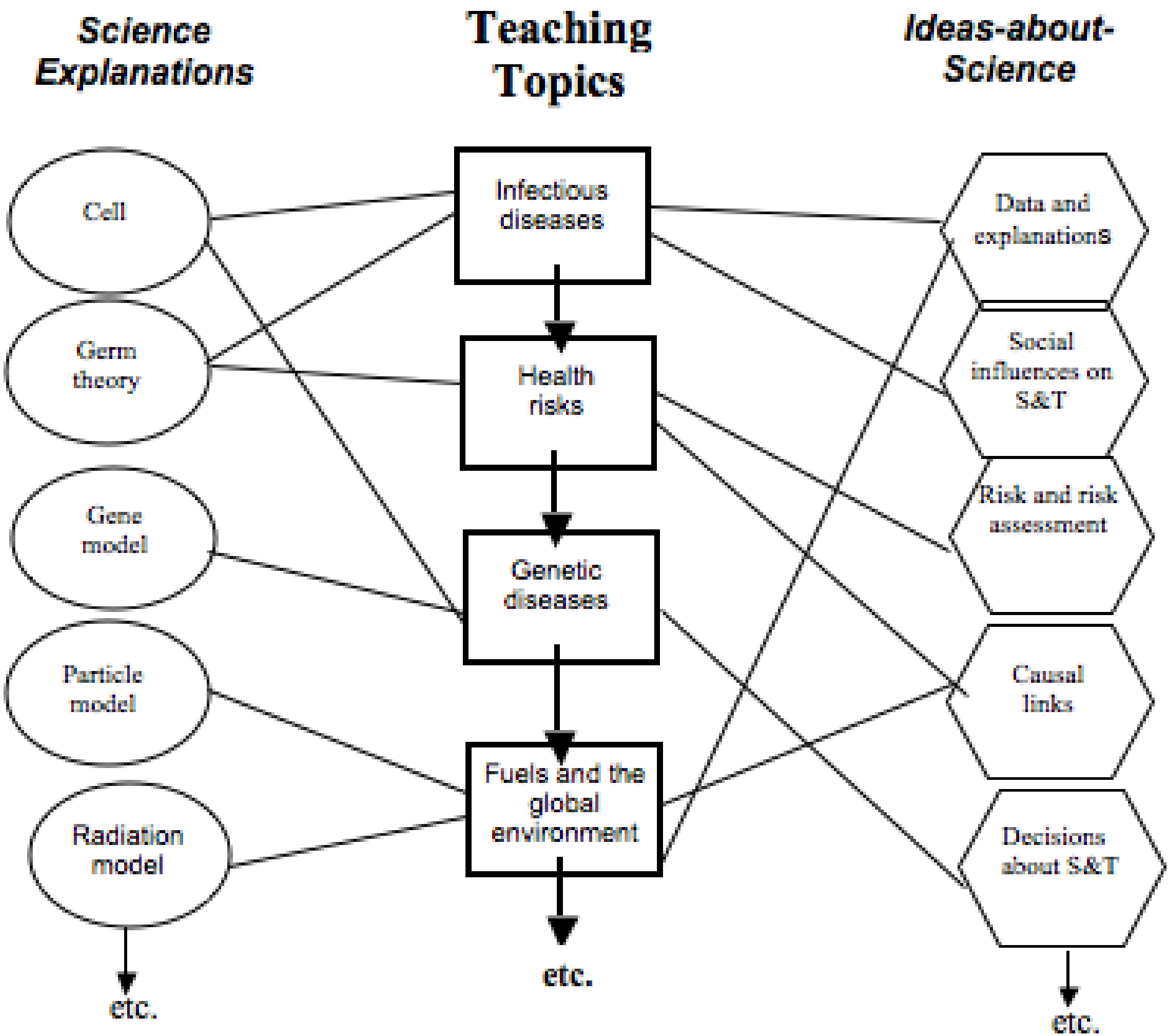


Fig 1: Diagram showing relationship between the Teaching Topics and the two major themes of the Science for Public Understanding course – Science Explanations and Ideas-about-Science

Hunt, A., & Millar, R. (Eds.). (2000). *Science for Public Understanding*. Heinemann Educational: London.

Osborne, J. F., Duschl, R., & Fairbrother, R. (2002). *Breaking the Mould: Teaching Science for Public Understanding*. Nuffield Foundation.

The Nature of Science & NGSS

Practices Crosscutting Concepts

- ▪ Scientific Investigations Use a Variety of Methods
- ▪ Scientific Knowledge is Based on Empirical Evidence
- ▪ Scientific Knowledge is Open to Revision in Light of New Evidence
- ▪ Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- ▪ Science is a Way of Knowing
- ▪ Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- ▪ Science is a Human Endeavor
- ▪ Science Addresses Questions About the Natural and Material World

Appendix H - One goal of science education is to help students understand the nature of scientific knowledge. This matrix presents eight major themes and grade level understandings about the nature of science. Four themes extend the scientific and engineering practices and four themes extend the crosscutting concepts. These eight themes are presented in the left column. The matrix describes learning outcomes for the themes at grade bands for K-2, 3-5, middle school, and high school. Appropriate learning outcomes are expressed in selected performance expectations and presented in the foundation boxes throughout the standards.

Understandings about the Nature of Science

Categories	K-2	3-5	Middle School	High School
Science is a Way of Knowing	▪ Science knowledge helps us know about the world.	▪ Science is both a body of knowledge and processes that add new knowledge. ▪ Science is a way of knowing that is used by many people.	▪ Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. ▪ Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. ▪ Science is a way of knowing used by many people, not just scientists.	▪ Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. ▪ Science is a unique way of knowing and there are other ways of knowing. ▪ Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. ▪ Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	▪ Science assumes natural events happen today as they happened in the past. ▪ Many events are repeated.	▪ Science assumes consistent patterns in natural systems. ▪ Basic laws of nature are the same everywhere in the universe.	▪ Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. ▪ Science carefully considers and evaluates anomalies in data and evidence.	▪ Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. ▪ Science assumes the universe is a vast single system in which basic laws are consistent.
Science is a Human Endeavor	▪ People have practiced science for a long time. ▪ Men and women of diverse backgrounds are scientists and engineers.	▪ Men and women from all cultures and backgrounds choose careers as scientists and engineers. ▪ Most scientists and engineers work in teams. ▪ Science affects everyday life. ▪ Creativity and imagination are important to science.	▪ Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. ▪ Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. ▪ Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. ▪ Advances in technology influence the progress of science and science has influenced advances in technology.	▪ Scientific knowledge is a result of human endeavor, imagination, and creativity. ▪ Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. ▪ Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. ▪ Technological advances have influenced the progress of science and science has influenced advances in technology. ▪ Science and engineering are influenced by society and society is influenced by science and engineering.
Science Addresses Questions About the Natural and Material World.	▪ Scientists study the natural and material world.	▪ Science findings are limited to what can be answered with empirical evidence.	▪ Scientific knowledge is constrained by human capacity, technology, and materials. ▪ Science limits its explanations to systems that lend themselves to observation and empirical evidence. ▪ Science knowledge can describe consequences of actions but is not responsible for society's decisions.	▪ Not all questions can be answered by science. ▪ Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. ▪ Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. ▪ Many decisions are **not** made using science alone, but rely on social and cultural contexts to resolve issues.

Knowledge Unproblematic-Problematic

- *Level 1* (Knowledge unproblematic) students view scientific knowledge as a collection of true beliefs about how to do something correctly or as basic facts. Scientific knowledge accumulates piecemeal through telling and observation which is certain and true.

- Carey, S. & Smith, C. (1993) On understanding the nature of scientific knowledge. *Educational Psychologist, 28,* 235-251.
- Smith, C., Maclin, D., Houghton, C., & Hennessey, M.G. (2000) Sixth-grade students' epistemologies of science: The impact of school science experience on epistemological development. *Cognition and Instruction, 18*(3), 285-316.

- *Level 2* (Transition) students view science knowledge as a set of tested ideas. Notions of explanation and testing hypotheses appear at this level. Here students' view science as figuring out how and why things work and absolute knowledge comes about through diligence and effort.

- *Level 3* (Knowledge problematic) students see scientific knowledge consisting of well-tested theories and models that are used to explain and predict natural events. Theories are seen as guiding inquiry, and evidence from experiments is not only used for/against hypotheses but theories as well. Theories and models are also seen as more or less useful rather than strictly right or wrong and that knowledge of the world is fundamentally elusive and uncertain.

Framework's PISA's Trilogy

"Understanding how science functions requires a synthesis of content knowledge, procedural knowledge, and epistemic knowledge."

- Content Knowledge – What we know
  - Core Ideas, Theories, Principles, Laws, etc.
- Procedural Knowledge – How we know
  - Concepts of Evidence
  - Methods that scientists use to ensure that their findings are valid and reliable.
- Epistemic Knowledge – Why we believe it
  - Knowledge of the various sets of criteria, rules and values held in the sciences and in engineering disciplines for deciding 'what counts';
  - Fair test, a precise and accurate measurement, systematic observations, testable hypotheses, etc.

- **Scientific Knowledge: PISA 2015 Terminology**
- This document is based upon a view of scientific knowledge as consisting of three distinguishable but related elements. The first of these and the most familiar is a knowledge of the facts, concepts, ideas and theories about the natural world that science has established. For instance, how plants synthesise complex molecules using light and carbon dioxide or the particulate nature of matter. This kind of knowledge is referred to as "**content knowledge**" or "knowledge of the content of science".
- Knowledge of the procedures that scientists use to establish scientific knowledge is referred to as "**procedural knowledge**". This is a knowledge of the practices and concepts on which empirical enquiry is based such as repeating measurements to minimise error and reduce uncertainty, the control of variables, and standard procedures for representing and communicating data (Millar, Lubben, Gott, & Duggan, 1995). More recently these have been elaborated as a set of "concepts of evidence" (Gott, Duggan, & Roberts, 2008).
- Furthermore, understanding science as a practice also requires "**epistemic knowledge**" which refers to an understanding of the role of specific constructs and defining features essential to the process of knowledge building in science (Duschl, 2007). Epistemic knowledge includes an understanding of the function that questions, observations, theories, hypotheses, models, and arguments play in science, a recognition of the variety of forms of scientific enquiry, and the role peer review plays in establishing knowledge that can be trusted.

Categories for Empirical Reasoning[a]	*Scientific Practices*[b]	*Verbs*[b]
Planning, Designing Data Acquisition	Selection of observation tools and schedule; Selection of measurement tools and units of measurement; Selection of question(s); Understanding interrelationships among central science concepts; Use central science concepts to build and critique arguments	Presents, Asks, Responds, Discusses, Revises, Expands, Challenges, Critiques. Knows, Uses, Interprets
Data Collection	Observing systematically, Measuring accurately, Structuring data, Setting standards for quality control, Posing controls, Forming conventions	Examines, Reviews, Evaluates, Modifies, Generates,
Evidence (Data Use)	Use results of measurement and observation; Generating evidence; Structuring evidence, Construct and defend arguments; Mastering conceptual understanding;	Extends, Refines, Revises, Decides, Categorizes,
Patterns (Modeled Evidence)	Presenting evidence; Mathematical modeling; Evidence-based model building; Masters use of mathematical, physical and computational tools;	Represents, Evaluates, Predicts, Discovers, Interprets, Manipulates, Build, Refines, Analyzes, Models,
Explanation	Posing theories; Conceptual-based models building; Search for core explanation; Considering alternatives; Understands how evidence and arguments based on evidence are generated; Revises predictions and explanations; Generates new and productive questions;	Builds, Refines, Represents, Interacts,

PCOI Components

- Deciding what and how to measure, observe and sample,
- Developing or selecting procedures/tools to measure and collect data,
- Documenting and systematically recording results and observations,
- Devising representations for structuring data and patterns of observations,
- Determining if:
  - (1) the data are good (valid and reliable) and can be used as evidence;
  - (2) additional or new data are needed or
  - (3) a new investigation design or set of measurements are needed.

Richard A Duschl and Rodger W Bybee (2014). Planning and carrying out investigations: an entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Educatio*n, 1:12

- Our hypothesis is that the 5D model provides struggle type experiences for students to acquire not only conceptual, procedural and epistemic knowledge but also to attain desired ‘ knowledge problematic’ images of the nature of science. Additionally, we further contend that PCOI is a more familiar professional development context for teachers wherein the 5D approach can help bridge the gap between the less familiar and the more complex practices such as building and refining models and explanations.

PCOI Grade 12 Goals

- Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (that is, a possible explanation that predicts a particular and stable outcome) based on a model or theory.
- Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.
- Decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data.
- Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls.

- Consider possible confounding variables or effects and ensure that the investigation’s design has controlled for them.
- Over a grade band (e.g., K-2 3-5, 6-8, 9-12) engagements with the planning and carrying out investigations should increasingly lead students to broaden and deepen the complexity of investigations.
- The *Framework’s* intent is to avoid students only doing investigations that present science knowledge and inquiry in ways that lead students to see scientific knowledge as non-problematic and thus where there is no struggle.
- Understanding the Nature of Science is gaining insights into the ‘struggles’ that are involved with building and refining knowledge, that is models, mechanisms, theories and explanations.