Harnessing Technology to Promote Science Learning and Scientific Literacy

Janice D. Gobert, Ph.D.
Senior Research Scientist
The Concord Consortium
Concord MA 01742
USA
jgobert@concord.org

www.concord.org

Modeling Across the Curriculum is funded by the the National Science Foundation and the U.S. Dept. of Education under a grant awarded to the Concord Consortium (IERI #0115699). Any opinions, findings, and conclusions expressed are those of the presenters and do not necessarily reflect the views of the funding agencies.

MAC Research Team

Principal & Co-Principal Investigators

Paul Horwitz, Concord Consortium, Principal Investigator
Janice Gobert, Concord Consortium, Co-PI & Research Director
Bob Tinker, Concord Consortium, Co-PI
Uri Wilensky, Northwestern University, Co-PI

Other main personnel

Barbara Buckley, Concord Consortium
Chris Dede, , Harvard University
John Willett, Harvard University
Amie Goldberg, Concord Consortium
Ken Bell, Concord Consortium, Project Manager
Sharona Levy, Northwestern University
Trudi Lord, Concord Consortium
Jody Clarke, Harvard University

Project Summary

- Funded in 2001 by the IERI (Interagency Education Research Initiative) program.
- This program emphasizes scalability, “evidence-based” research, and diverse populations- No Child Left Behind (NCLB).
- In our project, we place a heavy emphasis on using model-based technologies for inquiry as a means to promote scientific literacy.
- We are doing this in three domains: Biology, Physics & Chemistry.

What do we mean by scientific literacy?

- The book *Science for All Americans* (early 90s)-partly responsible for changing the way we think about WHO gets educated in science.
- If accessible to a broad range of learners, then how to make it so….focus on qualitative understanding of causal relationships underlying scientific phenomena.
- Knowledge in this form is more generative, transferable, and can be applied to everyday life which important to making decisions that effect our everyday lives (e.g., radon testing) .

Scientific Literacy (cont'd)… Perkins (1986)

- Content knowledge

- Process skills (i.e., inquiry, evaluation of evidence, communication, etc.). In MAC we add reasoning with models.

- Understanding the nature of science- I.e., that it is a dynamic process and that the current understanding of science is based our theories and methods with which we view them.

- Understanding More recently, it has been argued that understanding the nature of models is an important aspect of epistemology as well (Gobert & Discenna, 1996; Schwarz & White, 1998).

Inquiry need not preclude *accountability*!

That is, our technology allows for accountability by….

- Interactive curriculum and assessment materials…

  Computer-based activities pose challenging science problems, track students' actions as they solve them, and offer contextualized help.

- Embedded Assessment & Formative Assessment allows for students to get feedback WHEN they need it!

- Delivered over the Internet

  When a school registers with us its data is collected on our servers, automatically analyzed in real time, and used to create diagnostic assessments of students' conceptual understanding.

Overview to today…

- Research Questions
- Technology
  - Engine & software tools (BioLogica, Dynamica, Connected chemistry).
- Theoretical framework of MBTL.
  - Curricular Designs & Scaffolding Framework
- Assessments
  - Embedded assessments, Pre- and post-assessments, & surveys
- Logging Capacity & research with logs
- TPD & Teacher support
- Scalability

Research: Level 1- Case Studies with students

Case studies of students with software tools to assess …

~ conceptual progression of concepts (progressive model-building),

~ development of scaffolding framework

~ HCI issues.

Tools:

BioLogica (formerly GenScope, teaches Genetics)

Dynamica (teaches Newtonian /Mechanics)

Connected Chemistry (teaches Gas Laws)

Level 1 (cont'd): Teachers

Teacher Data collected with surveys

~ science teaching style, epistemological understanding, science "comfort" level, pedagogy with modeling.

Surveys

~ Teachers' epistemologies of models (adapted from Gobert & Discenna, 1997)

~ Teachers' science teaching survey (adapted from Fishman, 1999) and teachers' background questionnaire (The CC Modeling Team).

Research: Level 2- Classroom Research

Years 1-2

- 1) Further refinement of scaffolding framework.
- 2) Empirical studies of scaffolding framework.
- 3) Development of Assessments and Embedded Assessments
- 4) Development of Classroom communique and portal for teachers' use.

Research: Level 3- Longitudinal study in progress

Dependent Variables-

Cumulative gains on

- students' content knowledge,
- modeling skills,
- epistemological knowledge, and
- attitudes towards science.

Research: Level 4- Scalability

- What kinds of technology infrastructure and data logging capacities are necessary to provide high level, conceptually-based feedback to teachers about their students?
- What kinds of additional support (professional development, on-line support, etc) is necessary for teachers to succeed?
- How can we scale up from 3 partner schools to many schools across the U.S. where we deliver software and collect data from schools with modest support?

Forms of Knowledge, I-P & “Theoretical” Cognitive Affordances

- **Different knowledge forms have both different I-P requirements and cognitive affordances allowed based on degree of isomorphism between the “knowledge representation” and ”thing” it is representing.**

- **textual representations**, which describe in words, describe temporal seqences reasonably well but are poor at describing spatial/static aspects of science phenomena

- **diagrams/illustrations** good describe static/spatial features of phenomena but poor at describing causal and temporal features;

- **models** and **simulations** show the dynamic, causal mechanisms as well as the temporal features of a phenomenon.

- Thus text should offer fewer cognitive affordances than models but…

Student Difficulty in Learning from Models

…simply providing a diagram or model as an adjunct to text does not facilitate or promote deep understanding because:

- increased cognitive load on learners (Sweller, et al, 1990; Gobert, 1994) .
- students lack the necessary domain knowledge in order to guide their search processes through diagrams/models (Lowe, 1989; Head, 1984; Gobert, 1994; Gobert & Clement, 1999).

Thus …

- Students need scaffolding to guide their search processes, to support perceptual cues afforded by models, support inference-making from these perceptual cues.

- Our scaffolding is based on model-based teaching & learning (Gobert & Buckley, 2000)

Model-Based Teaching & Learning (Gobert & Buckley, 2000)

- Synthesis of research in cognitive psychology and science education
- Model-based learning as a dynamic, recursive process of learning by constructing & reasoning with mental models.
- Analogous to hypothesis development and testing seen among scientists (Clement, 1989).

Model-Based Learning in situ

Intrinsic Learner Factors

Epistemology of models

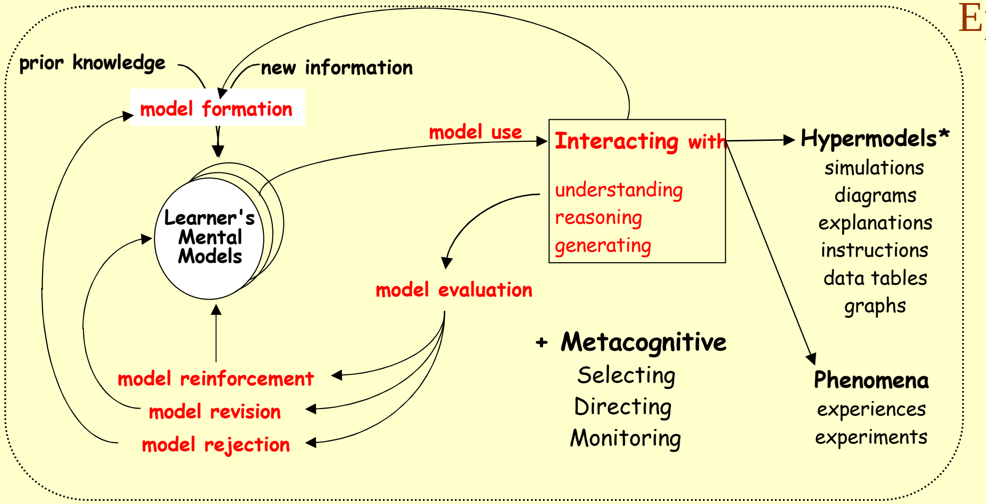
Attitudes & Self-efficacy

Intrinsic Teacher Factors

Epistemology of models

Teaching experience

Background



Classroom Factors

Implementation of MAC activity use (logged)

Teacher practices (reported via Classroom Communique)

Curriculum/Instructional design of MAC activities

- Follow MBTL framework (Gobert & Buckley, 2000) and
- Utilize a progressive model-building approach (White & Frederiksen, 1990; Raghavan & Glaser, 1995)

Model-Based Scaffolding Elements in MAC tools.

- **Representational Assistance** to guide students' understanding of the representations or the domain specific conventions in the domain.
- **Model pieces acquisition** to focus students' attention on the perceptual pieces of the representations and support students' knowledge acquisition about one or more aspects of the phenomenon (spatial, causal, functional, temporal).
- **Model pieces integration** to help students combine model components in order to come to a deeper understanding of how they work together as a causal system.
- **Model based reasoning** to support students' reasoning with their models.
- **Reconstruct, Reify, & Reflect** to support students to refer back to what they have learned, reinforce it, and then reflect to move to a deeper level of understanding.

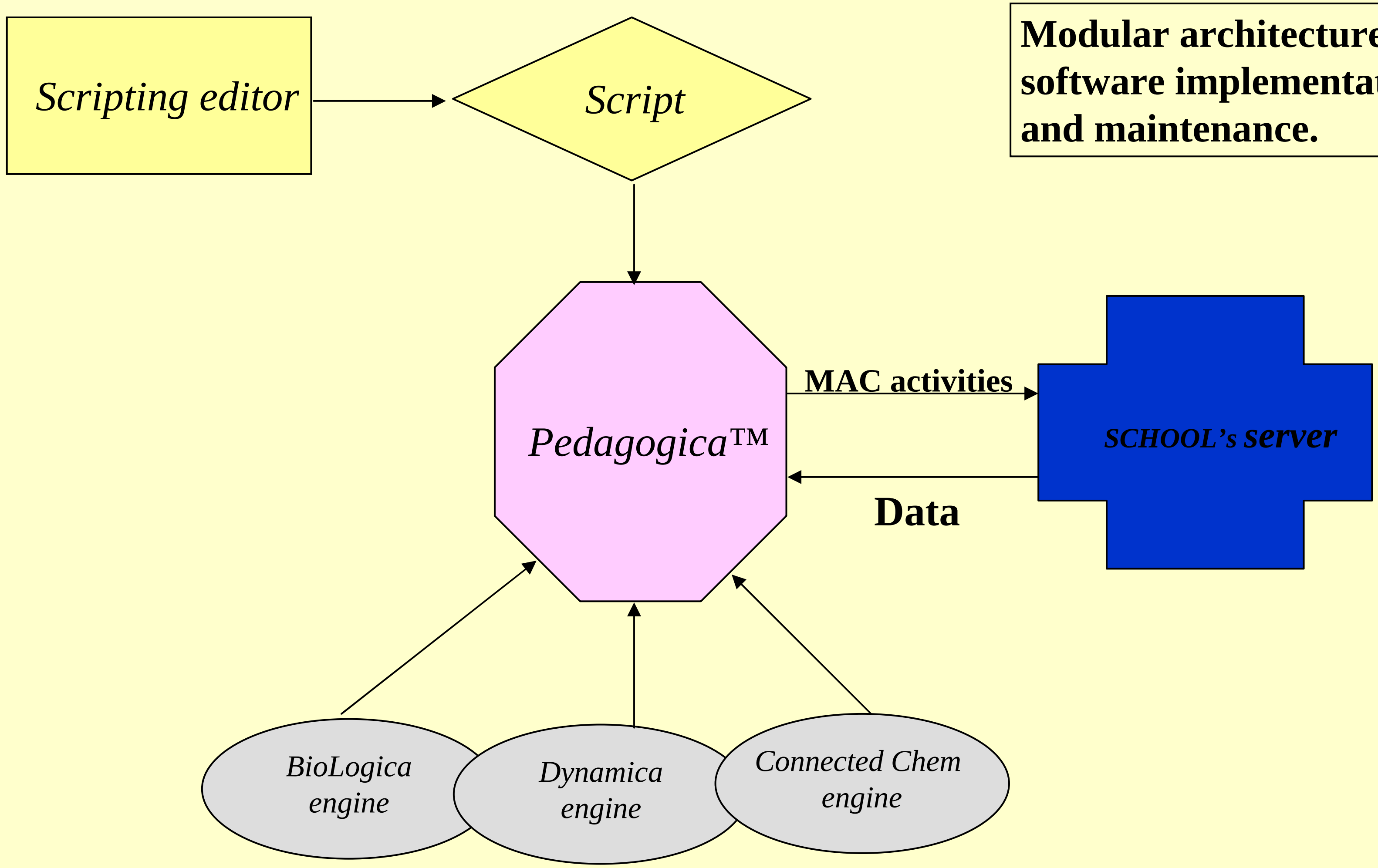
General MAC Scaffolds include

- Advance organizers to evoke prior knowledge and provide them with a structure to “fill in” the concepts
- Post organizers to reflect on and concretize what they have just learned.
- Orienting tasks to give the student a cognitive goal for the task.
- Glossary of terms provided within the software.
- Embedded assessment of understanding with “individualized” feedback to items in real time.

Effects of epistemology

- **MBTL and cognitive affordances focus primarily on factors dealing with student's cognitive processing but...**
- **Another important aspect is students' epistemological understanding of the nature of models and the nature of science b/c they**
  - **Influence knowledge integration (Songer & Linn, 1991).**
  - **affect reasoning with models (Gobert & Discenna, 1997; Gobert, 2004).**
- **Using log files we expect to detect differences in students' manipulations of MAC models depending on their epistemologies of models,**
  - **e.g., those with more sophisticated epistemologies may be more systematic in their manipulations with models.**
  - **Can use this data to track modeling skills over time.**

Technology Architecture



Modular architecture aids software implementation and maintenance.

New Logging Specs

Screen/task type	Logged by Pedagogica	Post processing
“Telling? screens ? text w or without diagrams	1. Time in screen	Reading content code
Screens with text and a manipulative task	1. Time in screen 2. Interaction time 3. Inputs to model	Nature of task Tries to success Systematicity
Screens with multiple choice questions	1. Time in screen 2. Answer 3. Correct answer	Type of question (assessment v. scaffolding)
Screens with essay questions	1. Time in screen 2. Typing time 3. Answer	Type of question (assessment v. scaffolding) “Quality?o f answer
Hint pop-ups	1. Time in Hint pop-up 2. Which hint accessed	

Technology Features & Affordances

TECHNOLOGICAL FEATURES

Pedagogica generates logs for every student interaction capturing student's…

- Actions and choices with models
- Data on duration and sequence
- Responses to questions

Embedded Assessments with models & questions…

- Generate profile for students
- "pivotal" points in curriculum
- Responses to questions

AFFORDANCES

"Hard" data -- used for implementation variables: which activities were used, pattern of use (consecutive or intermittent days)

Finer-grained data can be used for

- Filtering data
- Measure of systematicity
- Duration as covariate for level of treatment

These data will be used to derive student reports….

- Formative assessments
- Summative assessments

Technology Enhanced Formative Assessment for Teachers' Use

Explicit assessment items--Pre/post & Embedded Assessments

Log files as data…

- Time with manipulable models
- What steps they take with models (systematicity)
- Time on task/screen
- Time & tries to success
- What info or help they seek

Technology Enhanced Assessment

Interax with prior knowledge & epistemology

Model-Based Assessment

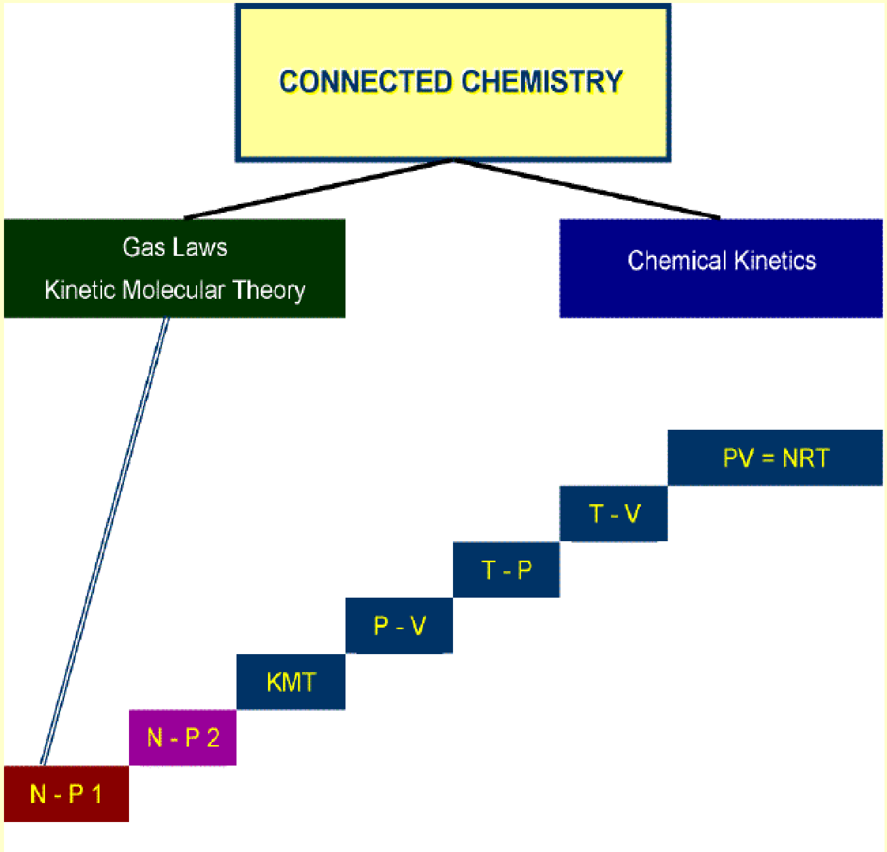
Can assess students understanding…

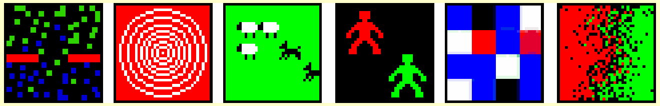
- Pieces of models (structure, i.e. parts, process, i.e., interax of parts to produce phenomena)
- Integration of pieces of models
- Success reasoning with model
- Skill at transferring model (i.e., reflection, solve problems, inferences).

Connected Chemistry

Goals

- ..challenge a *causal understanding* of Chemistry concepts within the framework of *complexity theory*.
- .. facilitate the distinction and connection between *model and reality* in science
- ..promote a coherent understanding of *micro-->macro* connections.

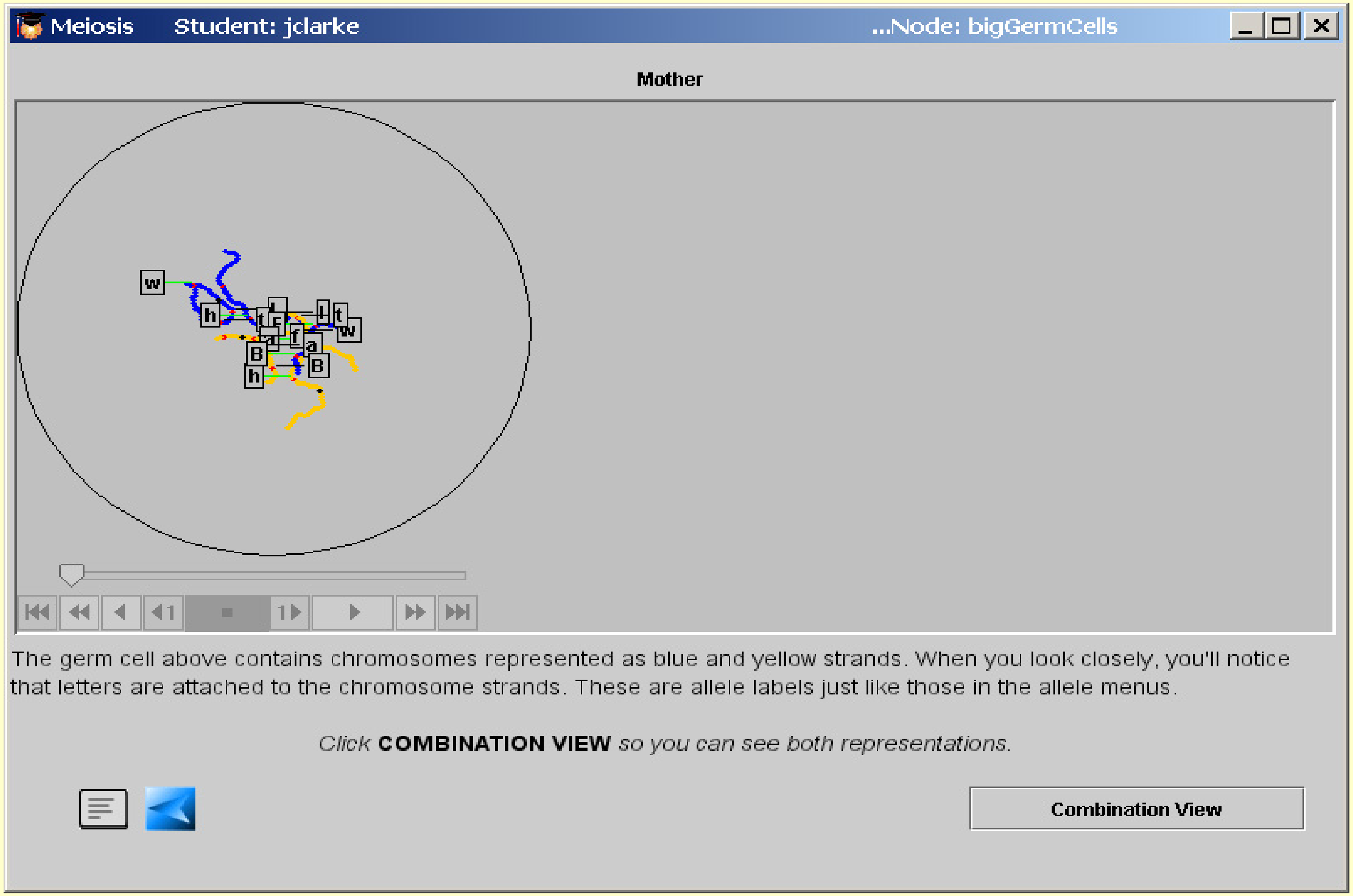




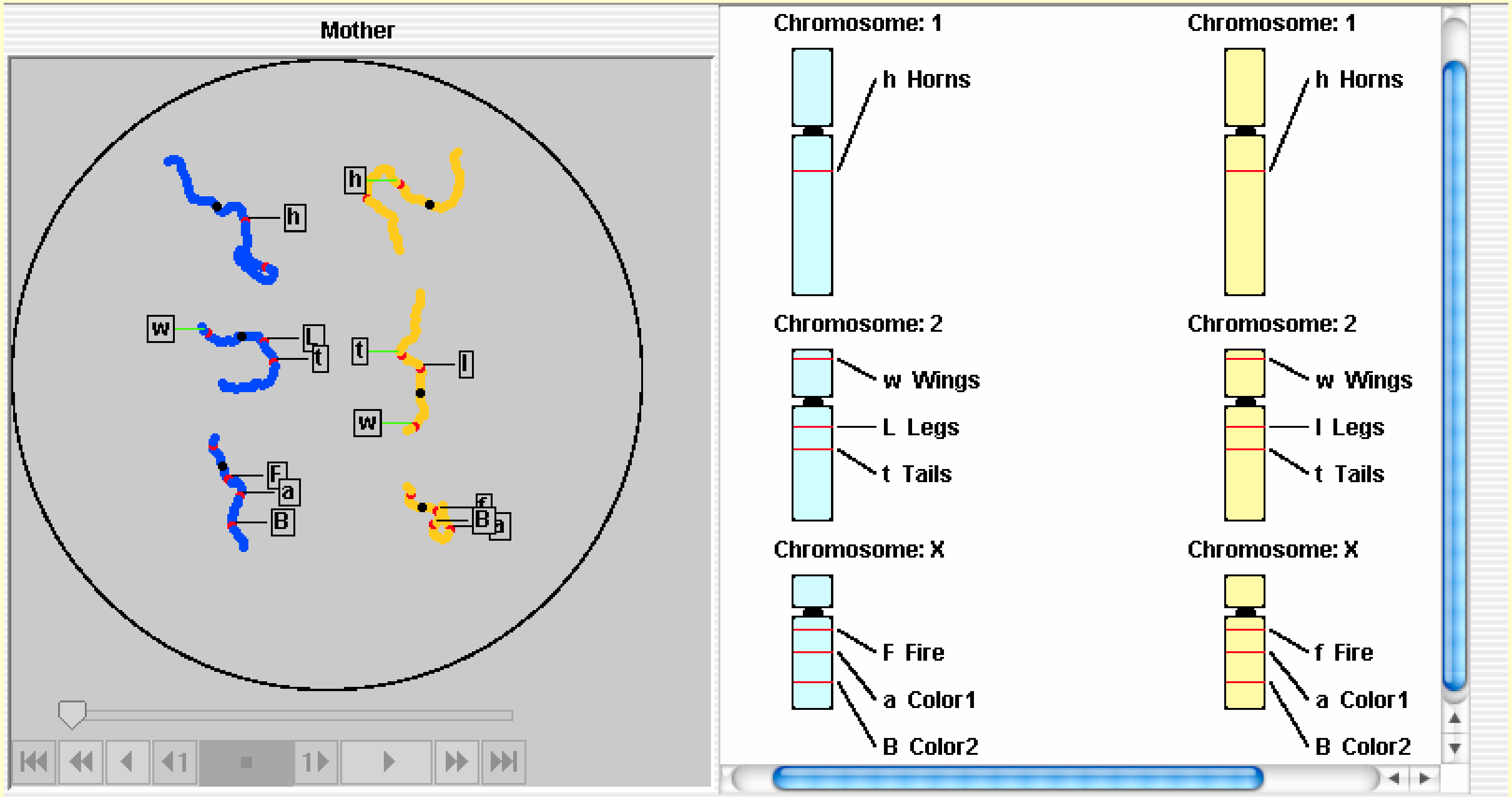
Technology Development in BioLogica

- Teaches transmission genetics (Mendelian genetics + intro to the molecular view).
- Multi-level model~ families, organisms, chromosomes, genes, DNA.
- Covers meiosis, mono-, dihybrid-, sex-linked, & polygenic characteristics.
- Allows for genetic investigations.

Examples of Scaffolding
Representational Assistance (DNA strands)
Students are told to click on magnifying glass to see germ cell.
Students see hidden structure and process (pieces of model).



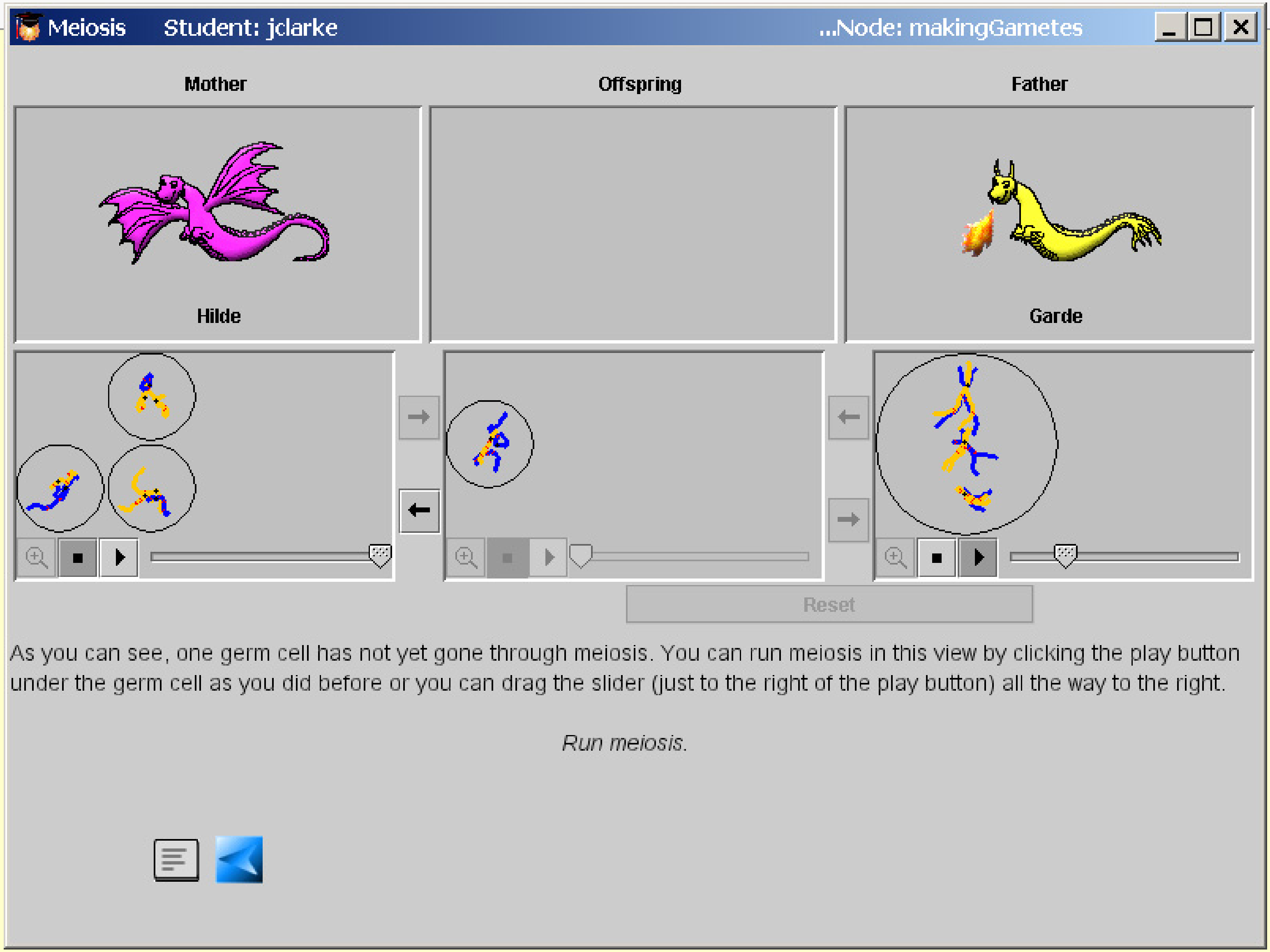
Representational Assist- Linking different representations



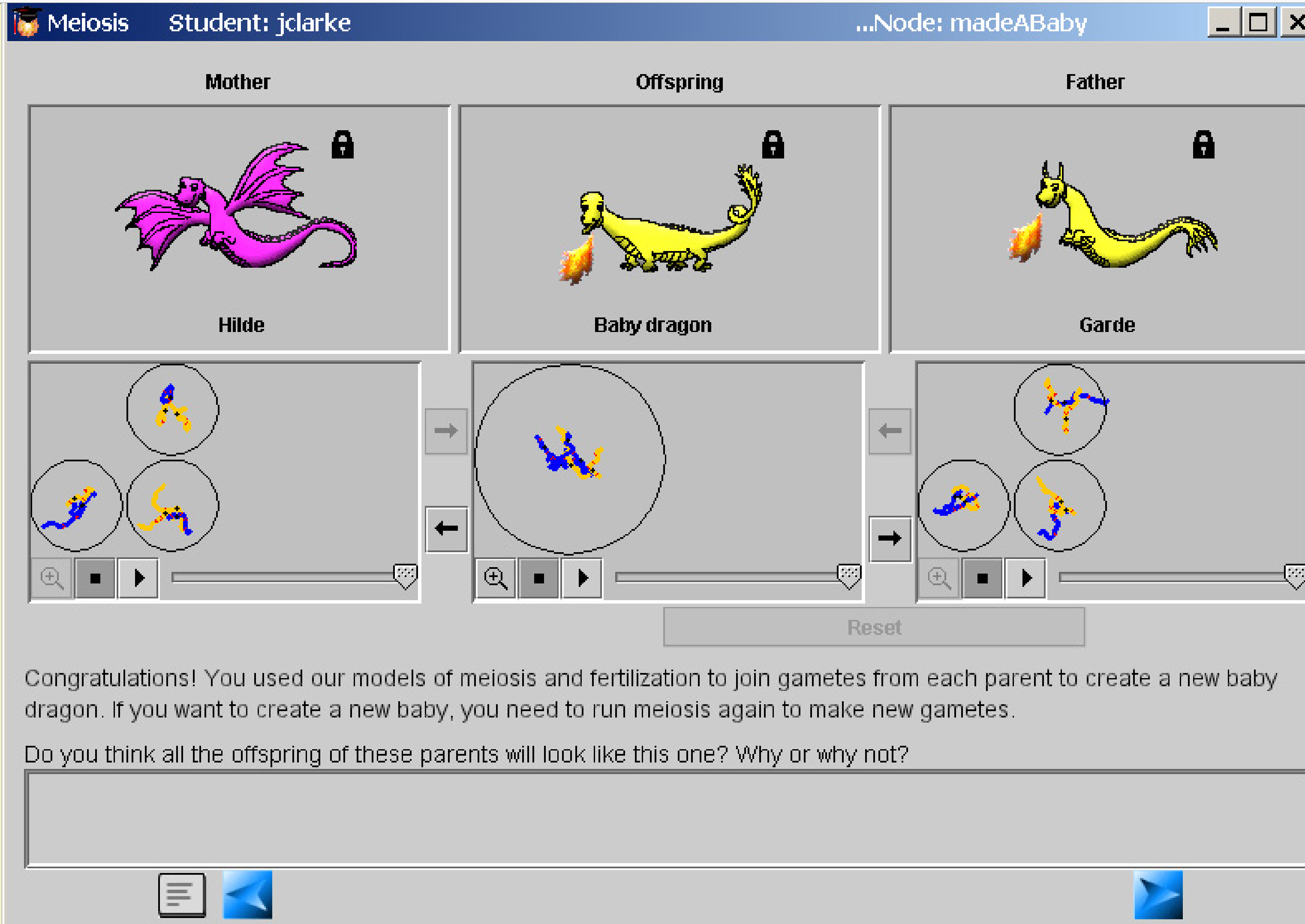
Compare the two representations of chromosomes. To make it easier, drag the strands in the cell (in the left panel) apart so they line up the way they do in the diagram at right.

Find the pair of X chromosomes in the cell and double click on one of X chromosome.

Making Gametes
Students click play and watch the gametes being made for both mother and father (Model Pieces Integration)

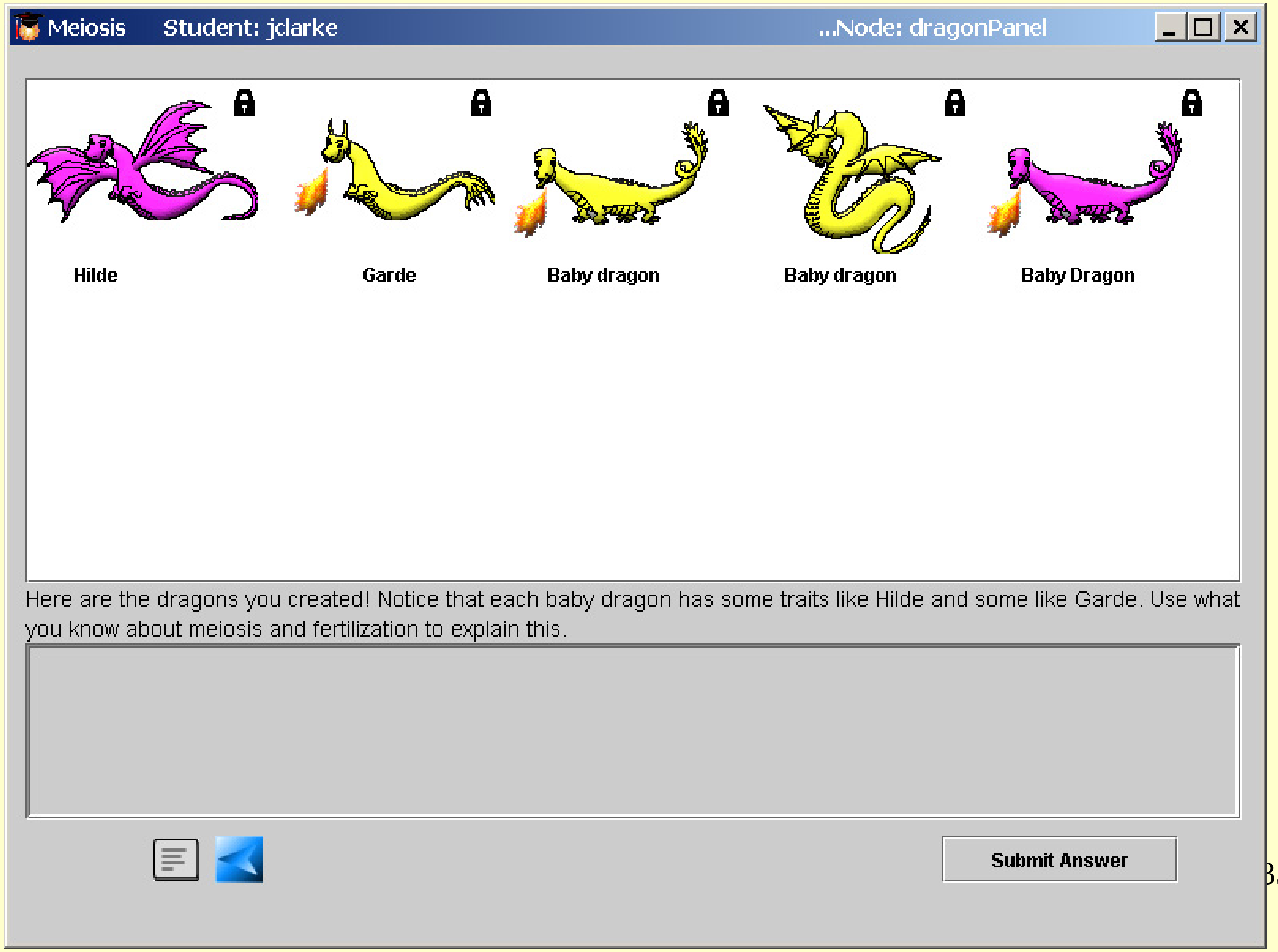


Model Piece Integration
After watching the process, now see the baby dragon (its physical representation).



Reconstruct, Reify, & Reflect.
Students see visually how a family might have different looking offspring with different traits. They are asked to reflect on the model.

In designer dragons (next activity) students now are given tasks: e.g., create a baby boy, create a dragon without horns. They run the model and choose gametes with specific chromosomes. This reinforces what they have learned and moves them to a deeper level of understanding (integration, RRR).



Technology Development in Dynamica

- Teaches Newtonian Mechanics in a qualitative way for Physical Science or Physics (CP, ACC, Hon's).
- Covers: Vectors, Vector addition, Force & Mass, Gravity, Momentum, Collisions, & Balancing Forces.
- Allows for experimentation & inquiry on these topics.

QuickTime?and a
Sorenson Video decompressor
are needed to see this picture.

Schools & Levels of Partnerships

- 3 Partner Schools-First 2 years of project ~1000 students, 22 teachers

  large urban, suburban, small urban, very mixed SES

- 10 Member Schools added in 2002

- Contributing Schools- adding these daily.

- As of last month, we are in
  - 115 schools,
  - 32 States,
  - 10 Countries total
  - Hong Kong?

Teacher Professional Development & Support

- Fall workshops (1-day)
  - Modeling
  - Research requirements
  - Data collection
- Spring workshops (1/2 day)
  - Data collection
  - Focus groups
  - New developments
- Web Portal, email, and phone

Portal functions

- Online presence for the MAC Project
- Software downloads
- Administrative features - Manage class rosters
- Help and support
  - Curriculum and activity guides
  - Frequently asked questions
  - Online community for Pedagogica teachers
- Classroom communiqués
- Reports for teachers, students and researchers
  - Classroom activity reports
  - Individual student reports
  - Student scores and answers to pre- and post-tests
  - Summary reports for all activities
    - *Coming soon*

Classroom Communiqué

- Communication between teachers and Concord Consortium
  - Specific to each topic and class
- Assigned Activities
  - Which Pedagogica activities did you ask students to use?
- Preparation
  - What work was done in class to prepare for Pedagogica use?
- Follow-up
  - How will you follow-up in the classroom?
- Comments
  - What issues,if any, did your students have while using Pedagogica?

The Concord Consortium

Class Overview Report

Class Report

Biology Period 2 at High School

Teacher: Mr. R

Have you filled out your Classroom Communiqué?

Topic: Genetics

Student Reports

Click ⊞ to enable an activity or click ⊟ to disable an activity.

Key:	
Status	**Availability**
● Report(s) Available	☐ Activity Enabled
● Working on Activity	▒ Activity Disabled

	Modeling Survey	Learning Survey	Genetics Pre-Test	Introduction	Rules	Meiosis	Monohybrid	X-linkage	Dihybrid Cross	Scales	Mutations	Horns Dilemma	Mutation Inheritance	Invisible Dragons	Plates	Genetics Post-Test	Genetics Modeling Survey Post Test	Genetics Learning Survey Post Test
Student #5997	●	●	●	●	●	●	●	●	●							●	●	●
Student #5998	●	●	●	●	●	●	●	●								●	●	●
Student #5999	●	●	●		●	●	●	●	●							●		
Student #6000	●	●	●	●	●	●	●	●	●							●	●	●
Student #6002			●	●	●	●	●											
Student #6003	●	●	●	●	●	●	●	●	●							●		
Student #6004	●	●	●	●	●	●	●	●	●							●	●	●
Student #6006	●	●	●	●	●	●	●	●	●							●	●	●
Student #6188	●	●	●	●	●	●	●	●	●								●	●

Internet

Pre/Post Test Summary

Pre/Post Test Report

Teacher: Mr. R

Class: Biology Period 2

School:

Activity: Genetics Pre-Test

	Student #5997	Student #5998	Student #5999	Student #6000	Student #6002	Student #6003	Student #6004	Student #6006	Student #6188	Student #6007	Student #6008	Student #6009	Student #6010	Student #6011
Question 1	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✓ / --	✗ / ✗	✗ / ✗	✓ / ✗	✗ / --	✗ / ✗	✗ / ✗	-- / ✗	✗ / ✗	✗ / ✗
Question 2	✗ / ✗	✓ / ✗	✗ / ✗	✗ / --	✗ / --	✓ / ✗	✗ / ✗	✓ / ✓	✗ / --	✓ / ✓	✓ / ✓	-- / ✓	✓ / ✓	✓ / ✓
Question 3	✗ / ✓	✗ / ✗	✗ / ✗	✗ / --	✗ / --	✗ / ✓	✗ / ✓	✓ / ✗	✓ / --	✗ / ✓	✓ / ✓	-- / ✗	✓ / ✓	✓ / ✓
Question 4	✗ / ✗	✗ / ✗	✓ / ✓	✗ / --	✗ / --	✗ / ✓	✗ / ✓	✗ / ✓	✗ / --	✗ / ✗	✗ / ✗	-- / ✗	✗ / ✗	✓ / ✗
Question 5	✓ / ✓	✓ / ✗	✗ / ✓	✓ / --	✗ / --	✗ / ✗	✗ / ✓	✗ / ✓	✓ / --	✓ / ✓	✓ / ✓	-- / ✓	✗ / ✗	✓ / ✓
Question 6	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / --	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / ✗	✗ / ✗	-- / ✗	✗ / ✗	✗ / ✗
Question 7	✗ / ✗	✗ / ✗	✗ / ✓	✗ / --	✗ / --	✗ / ✗	✗ / ✓	✓ / ✗	✗ / --	✗ / ✗	✓ / ✓	-- / ✗	✗ / ✗	✗ / ✗
Question 8	✓ / ✓	✗ / ✓	✓ / ✗	✓ / --	✓ / --	✓ / ✓	✓ / ✗	✗ / ✓	✓ / --	✓ / ✓	✓ / ✓	-- / ✓	✓ / ✓	✓ / ✓
Question 9	✗ / ✓	✓ / ✗	✗ / ✗	✗ / --	✗ / --	✗ / ✗	✗ / ✓	✗ / ✗	✗ / --	✓ / ✗	✗ / ✗	-- / ✗	✓ / ✓	✗ / ✓
Question 10	✓ / ✓	✗ / ✓	✗ / ✗	✗ / --	✓ / --	✗ / ✗	✓ / ✗	✗ / ✗	✓ / --	✓ / ✓	✓ / ✓	-- / ✗	✓ / ✓	✓ / ✗
Question 11	✓ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / --	✓ / ✓	✓ / ✗	✓ / ✗	✓ / --	✓ / ✗	✗ / ✗	-- / ✓	✗ / ✓	✓ / ✗
Question 12	✗ / ✗	✗ / ✓	✗ / ✓	✓ / --	✗ / --	✗ / ✗	✗ / ✗	✗ / ✓	✗ / --	✗ / ✗	✗ / ✓	-- / ✗	✗ / ✗	✓ / ✓
Question 14	✗ / ✓	✓ / ✗	✗ / ✓	✓ / --	✗ / --	✓ / ✗	✗ / ✗	✗ / ✓	✓ / --	✓ / ✓	✓ / ✓	-- / ✗	✗ / ✗	✗ / ✗
Question 13	✗ / ✗	✓ / ✓	✗ / ✗	✓ / --	✗ / --	✓ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / ✗	✓ / ✓	-- / ✗	✓ / ✗	✗ / ✗
Question 15	✓ / ✓	✗ / ✓	✗ / ✓	✓ / --	✓ / --	✗ / ✗	✗ / ✗	✗ / ✓	✓ / --	✗ / ✗	✗ / --	-- / ✓	✓ / ✓	✗ / ✓
Question 16	✓ / ✓	✗ / ✗	✓ / ✓	✓ / --	✓ / --	✓ / ✓	✗ / ✓	✗ / ✓	✓ / --	✗ / ✓	✓ / --	-- / ✓	✓ / ✓	✗ / ✓
Question 17	✓ / ✓	✓ / ✗	✓ / ✓	✓ / --	✓ / --	✗ / ✓	✗ / ✗	✗ / ✓	✓ / --	✗ / ✓	✓ / --	-- / ✓	✓ / ✓	✗ / ✓
Question 18	✗ / ✓	✗ / ✗	✓ / ✓	✓ / --	✗ / --	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / ✗	✓ / --	-- / ✗	✓ / ✓	✗ / ✓
Question 19	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / --	✗ / --	✗ / ✗	✗ / ✗	✗ / --	✗ / ✗	✗ / --	-- / ✗	✗ / ✗	✗ / ✗
Question 20	✗ / ✗	✗ / ✗	✗ / ✗	✗ / --	✗ / --	✗ / --	✗ / ✗	✗ / ✗	✗ / --	✗ / ✗	✗ / --	-- / ✗	✗ / ✗	✗ / ✗
Question 21	✓ / ✓	✗ / ✗	✗ / ✓	✓ / --	✗ / --	✗ / --	✗ / ✓	✗ / ✗	✗ / --	✗ / ✓	✗ / --	-- / ✗	✓ / ✗	✓ / ✗

Internet

Student Pre/Post Test Report

Home Portal Reports Pre/Post Test Report

Pre/Post Test Report

Pre-Test Summary	Post-Test Summary
Number Correct: 23	**Number Correct:** 19
Total Problems: 55	**Total Problems:** 55
Score: 42%	**Score:** 35%

X / √ **51. Redgreen colorblindness in humans is an Xlinked recessive trait. Males are more likely to be redgreen colorblind than females because redgreen colorblindness is (assume Male XY, Female XX)**

Pre-Test	Post-Test
• dominant in one sex and recessive in the other.	• dominant in one sex and recessive in the other.
• influenced by the hormones present in the individual.	• influenced by the hormones present in the individual.
• **caused by an allele that is part of the X-chromosome and the male has only one X-chromosome.**	• **caused by an allele that is part of the X-chromosome and the male has only one X-chromosome.**
• **caused by an allele that is part of the Y-chromosome and the female does not have a Y-chromosome.**	• caused by an allele that is part of the Y-chromosome and the female does not have a Y-chromosome.

In terms of our theoretical goals…

- This research extends a current vein of progressive model-building in science education (cf., Raghavan & Glaser, 1995; White & Frederiksen, 1990) by having students engage in deep inquiry with technology-based models.
- Furthermore, all tasks are scaffolded using a model-based scaffolding framework in order to promote both deep understanding of the content as well as promote a deep understanding of the nature of models in science.
- It is believed that rich, scaffolded model-based tasks such as these engages students in authentic scientific inquiry, and as such can significantly impact content knowledge, inquiry skills, and scientific literacy.

In terms of IT, we are leveraging technology ….

…..As a bird's eye view into the black box.

To develop detailed understanding of students' model-based learning with manipulable models---> Important for the Learning Sciences.

For formative and summative assessment for teachers' and students' use---> Important for Science Education & practice.

To scale our tools to many schools worldwide--->Important for students' learning, scalability, & sustainability.

MAC is available…

- Become a contributing school, mac.concord.org
- Some MAC activities & others available through TELS (telscenter.org)
- For more information, go to www.concord.org
- See March ‘04 issue of JSET (www.jset.unlv.edu)
- Contact me at jgobert@concord.org

- THANK YOU!