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Interactive Curriculum Based on Models of Mind & Brain

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Abstract. What does it mean for curriculum to be interactive? It encourages student engagement and active participation in both individual and group work. It offers teachers a coherent set of materials to choose from that can enhance their classes. It is the product of on-going development and continuous improvement based on research and feedback from the field. This paper will introduce work in progress from the Center for Excellence in Education, Science, and Technology (CELEST), an NSF Science of Learning Center. Among its many goals, CELEST is developing a unique educational curriculum, an interactive curriculum based upon models of mind and brain. Teachers, administrators, and governments are naturally concerned with how students learn. Students are greatly concerned about how minds work, including how to learn. CELEST aims to introduce curricula that not only meet current U.S. standards in mathematics, science, and psychology but also influence plans to improve those standards. Software and support materials are in development and available at http://cns.bu.edu/celest/private/. Interested parties are invited to contact the author for access.

Keywords: CELEST, curriculum, pedagogy, interactive software, computational neuroscience, learning science

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Overview

Along with research in basic science, the Center for Excellence in Education, Science, and Technology (CELEST)[1] is developing innovative curriculum based on models of how the brain learns to control behavior. How our minds work is a great interest to students of all ages as part of their self-discovery; however, models of mind and brain are not incorporated into science and mathematics curriculum for primary and secondary students. CELEST innovations are intended to create a long-term impact on knowledge, research, policy, and practice in the learning sciences. CELEST is solving fundamental problems of learning by integrating experimental and computational brain science, biologically inspired technology, and classroom innovation. A brief description of the Center has been published by Principle Investigator Stephen Grossberg[2]. The focus of this paper is to describe progress made in curriculum development since the Center's inception as a National Science Foundation Science of Learning Center[3] in October, 2004. The software and support materials are in

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[1] See home webpage http://cns.bu.edu/CELEST/ for more information about the Center and its various programs.
[2] Grossberg, S. (2005) outlines the various basic and applied research thrusts within CELEST.
[3] See home webpage www.nsf.gov/slc for more information about the agency and its currently sponsored centers.

development and available at http://cns.bu.edu/celest/private/. Interested parties are invited to contact the author for access.

The curriculum is interactive in a number of dimensions. Modules are developed in layers, with the first requiring no specialized previous knowledge. Subsequent layers introduce more advanced materials in a self-contained way. CELEST curriculum supports inquiry-based active learning; discussion, experiment, data collection and analysis, and modeling are integrated to help students achieve a deep understanding of both content and pedagogy. Students learn specific content in science and mathematics related to how *they* learn, identify and address subject-specific misconceptions, and develop the ability to apply knowledge to new situations. One might expect that the software has to be competitive with commercial games in order to hold the interest of students because they would have high expectations based on their experience with commercial games. However, simple interactive software about perception, cognition, action and emotion motivates students to learn about themselves and others. In addition, the same learning tools can be used to teach practicing scientists and other adult learners about interdisciplinary mind-brain research.

Methods and materials

CELEST curriculum is designed with two goals in mind. First, develop curriculum materials that can be directly used not only to satisfy present curriculum requirements, but also to employ exciting new examples derived from models and data about mind and brain. These modules may be presented in larger curriculum units, encompassing one or more classes, depending upon the curriculum material that is being augmented. Second, develop curriculum materials that can be used to excite students to study many areas in the present curriculum that may seem dry or uninspiring without them. We call the latter materials "stealth modules." Such modules may take only 15 - 30 minutes to be presented as part of a more traditional lesson plan. Both sorts of modules might inspire students to learn more mathematics and science, and to enter previously unconsidered careers, including careers in science and teaching. In addition, various courses in CELEST departments at the university level are being revised or created to include new material about models of learning.

Each curriculum module is designed to fulfill several situation scenarios[4] including use by both teachers and students at various levels of instruction; field testing ensures the usability of the curriculum at different instructional levels. CELEST curriculum has been developed with an explicit alignment to the principles discussed in How People Learn: Brain, Mind, Experience, and School[5]. Interaction is critical across the perspectives on learning environments defined in HPL: student-centered, knowledge-centered, assessment-centered, and community-centered dimensions of effective teaching and learning interact through their alignment. Using CELEST curriculum, students will think about how they learn. Indeed, the process of thinking about thinking is a cornerstone of modeling mind and brain; while experimental data often suggest or validate a particular model, thought-experiments also give rise to models or to modifications of them.

Besides supporting teachers and students who appreciate how brain affects behavior and behavior affects brain, CELEST educational objectives include the development of a new generation of scientists who participate in learning research and educational outreach (scientist-educators). A key

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[4] The formal technique of use cases helped specify requirements for both print materials and software; see Kulak and Guiney (2000).

[5] Sponsored by the National Academy of Science and the U.S. Department of Education, this general science of learning framework is a useful reference for designing and delivering educational improvements (Bransford et al. 2000).

element of this integration is the CELEST incubator course project: as part of their coursework, graduate students develop classroom, textbook, and web-based educational materials for future incorporation into CELEST curriculum. In addition, graduate students and post-docs have worked on the modules outside of class for sustained periods of time. Along with input from faculty, this is a top-down approach to curriculum development; in other words, the content of the curriculum follows research.

CELEST curriculum is universally relevant and readily transferred to everyday experience; however, the key to its acceptance and utility will be its fit to the intended audience. Calibrated to the skill level of the intended audience, CELEST curricula include interdisciplinary information that unifies behavioral data, brain data, theoretical concepts, mathematical models, and computational methods. Extensive field tests by teachers and students interacting with the curriculum are necessary before the educational materials are distributed on the web and used systematically in classrooms. This is a bottom-up approach to curriculum development.

Planned formal research on CELEST educational materials should lead to results that will help to improve classroom practice; for example, an impact on student learning and study skills. In field trials, CELEST curriculum has already excited and motivated students to learn about and become more conscious of themselves and others. Future activity might include pre-service programs for prospective teachers, field-days for learning about mind and brain, and integration with museum exhibits.

CELEST has and will continue to host workshops for secondary teachers and undergraduate teaching faculty. These programs have included research experiences for teachers, summer undergraduate research fellowships, and a summer program for Boston-area minority high-school students. CELEST is continuing to develop educational modules in conjunction with middle and high school math and science teachers. The effort began two years ago: five teachers participated in 8-week summer programs in 2005 and 2006. During the two-week workshop[6] in 2007, teachers were introduced to the curriculum modules and participated in discussions with researchers on the connections between the education modules and CELEST basic science research. During the second week, they engaged in a "How People Learn" workshop, and developed lesson plans that adapted CELEST curriculum for use in their classrooms.

Curriculum Development: Interim Results

The modules under development are focused on perception, cognition, emotion and action. Since nearly half of the brain is dedicated to visual processing, *Brightness Lab* begins the systematic study of vision. Given a goal, how do we decide to move as a reaction to sensory (visual) input? *Obstacle Avoidance Navigation* explores the question of reactive movement as opposed to memory guided movement. We begin the exploration of memory and learning by studying *Sequence Learning* of numerical lists and continue through an examination of *Recognition*. Finally, since perception, action and cognition are all mediated by emotions, we begin to address them in the context of *Associative Learning* by studying adaptive timing to an aversive stimulus. After sufficient field-testing and revision based on feedback and research results, these modules will be released for general use on the CELEST main website at http://cns.bu.edu/CELEST/. The following table lists the modules being tested in classrooms with a note naming the scientist-educator contributors (the modules are described in greater detail later):

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[6] July 9-20, 2007 at Boston University; see http://cns.bu.edu/CELEST/curriculummaterials/summer.html for details.

Curriculum module	**Description**
Brightness Lab[7]	Perception of light and dark surfaces. Through a study of visual illusions, normal perception, anatomy and physiology, this module teaches students about how we see bright and dark surfaces. Users perform a perceptual experiment in which they match the brightness of different regions on the screen and then analyze the results. A neural network model of brightness perception uses an ordinary differential equation to characterize the rate of change in neurons that leads to brightness perception. Students are guided through the construction of the neural network model using thought-experiments, an introduction to terminology, graphing symbols, and interactions among excitatory and inhibitory neural connections.
Associative Learning[8]	Linking stimulus and response. The ability to learn temporal conditioning is a critical survival competence because it enables the learning of which earlier events predict later consequences, as well as which event combinations are not causative. In this way, the individual can make the optimal choices for successful, adaptive behavior. Students begin with an experimental, interactive task that simulates aversive conditioning. Student performance data is presented in multiple formats for analysis. The module uses a neural network model eye-blink conditioning to develop a deeper understanding of the types of memory.
Sequence Learning[9]	Performing/recalling a linked list of behaviors/items. This module studies the interaction of working memory and long-term memory related to temporal order processing. Students collect experimental data on their own working memory span, perform an analysis thereof, and test the negative effect of distractions and the positive effect of chucking on their memory span. There is also an opportunity to use an advanced neural network models of sequence learning.

Other CELEST modules are in development but not yet ready for testing:

Curriculum module	**Description**
Obstacle Avoidance[10]	Sensory guided movement to avoid obstacles and attain goals. Given a goal, how do we decide to move as a reaction to sensory input? Navigation by humans often relies on an ability to visually detect where things are in the environment, and plan a path without colliding with obstacles. This module explores several aspects of obstacle avoidance navigation, using 2D interactive software.
Recognition[11]	Object categorization. This module teaches students how humans and machines learn to recognize objects and events. Students categorize different vehicles in a “Cars” database while the computer uses specialized machine learning algorithms such as ARTMAP and KNN. Other databases and algorithms can be used in future.

After building on previous knowledge by discussing appropriate challenge questions, and identifying and addressing misconceptions related to the topic, students conduct an experiment to collect data on

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[7] Faculty advisors: Ennio Mingolla, Steve Grossberg. PhD students & Post-Docs: Levin Kuhmann, Liang Fang, Bret Fortenberry; Nico Foley, Tren Huang, Tony Vladusich.

[8] Faculty advisor: Dan Bullock. PhD students: Can Tan; Jasmin Leveille, Himanshu Mhatre.

[9] Faculty advisors: Dan Bullock, Steve Grossberg, Bob Sekuler. PhD students & Post-Docs: Lance Pearson, Max Versace, Brian Gold; Sohrob Kazerounian, Matt Silver.

[10] Faculty advisors: Steve Grossberg, Mike Hasselmo. PhD students & Post-Docs: David Elder, Krishna Srihasam, Eric Zilli, Randal Koene; Andrew Browning, Bret Fortenberry, Lingqiang Kong.

[11] Faculty advisors: Gail Carpenter, Steve Grossberg. PhD students & Post-Docs: Rushi Bhatt, Arash Fazl; Gennady Livitz, Eugene Zaydens, Anatoli Gorchetchnikov.

their individual psychophysical data. Students analyze the data and need to make choices about the best way to present, clarify and interpret it relative to their hypotheses. Depending on their educational level, students will be able to run simulations of models of mind, brain, and behavior and discuss their results. The software has various settings that modify both run-time and experimental parameters for customization. This feature supports students who want to study a module in more depth or design science or math projects that investigate how the mind and brain work. Teachers can incorporate part or all of a module as they design their lesson plans. Each curriculum module has standard documentation that supports instruction:

(1) *Teacher Instructions* contains curriculum integration guidelines written by practicing middle and high school teachers and includes the following sections: Introduction, Intended Audience, Adjustment/ Adaptation, Placement in the Curriculum Time, Resources, Electronic Equipment, Goals and Objectives, Instructional Activities, and Assessments with rubrics and answer keys.

(2) *Background and Theory* contains motivation, anatomical knowledge, and theoretical knowledge.

(3) *Software User's Guide shows* how to use the software curriculum with screen shots and a description of functional use cases.

(4) *Class Presentation* contains a PowerPoint presentation for the teacher to use in class to motivate and instruct.

(5) *Class Materials* contains hands-on, structured activities and various levels of assessment instruments for students.

Brightness Lab

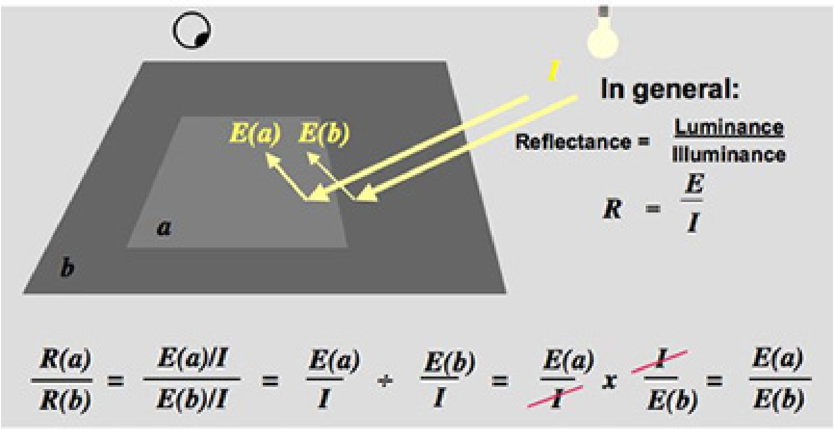
The Brightness Lab module integrates math and science curricula in a study of brightness perception. The module begins by addressing misconceptions about vision and the perception of visual illusions. After an intuitive and qualitative presentation of brightness perception through physical models similar to actual scenes, eye and brain anatomy are presented. The module gradually introduces quantitative models, beginning with ratios, to explain the phenomenon and deepen understanding. Thus, models range from those similar to everyday experience to increasingly abstract concepts and mathematical formalizations.

The specific topic in this module is the brightness contrast effect wherein squares of the same shade of gray appear to be different when embedded in different backgrounds. The first part of the software interaction serves to clarify the phenomena in concrete terms. A split screen is presented with the left side of the screen containing “reference” concentric squares and the right side an inner “target” square within an outer square (see Figure 1).

Figure 1: The surrounding context impacts our perception of brightness. The reference and the target inner square patches are the same shade of gray.

The reference stimulus presents the inner and outer squares filled-in with different but fixed gray colors. The target square is also gray, but the grayscale is adjustable by the student. The student must adjust the shade of gray of the target square to match the appearance of the color-fixed inner reference square. A series of reference stimuli are presented randomly from an already-prepared set of reference colors. Once the student perceives a match, the student instructs the computer to record his/her choice of the color and continue to the next reference item to match. This is repeated a number of times over a set of reference colors. Each student records a luminance measurement of the reference and matched target colors and computes their ratio. At the end of a session the student is provided with a chart of the results of the session. Depending on the level of the course of study, the student will graph and analyze the different variables in the experiment to discover patterns and reach conclusions that will allow them to explain brightness perception and make predictions about brightness contrast and constancy.

Thus, building on an intuitive sense of brightness perception, the student discovers various properties about it through interactive hands-on experiences. The module presents a sequence of concrete and abstract models that represent and explain key phenomena (for example, brightness contrast and brightness constancy[12]), and are structured towards progressive formalization of knowledge. The mathematical models range from (1) simple ratios of measures of reflected light to illustrate brightness contrast to (2) complex fractions that explain brightness constancy, to (3) scatter plots and (4) linear and nonlinear regression analysis. Students are introduced to concepts from discrete mathematics such as (5) directed graphs to design a neural network diagram. This exercise leads to the (6) representation of the dynamic values of the nodes in the network that represent the biological substrate for vision and influences on their rates of change. Then, (7) equilibrium analysis using simple algebra can be performed (the equation for the rate of change is set to zero) to study the properties of a mass-action neural network model in terms of its parameters and variables; finally, (8) calculus notation can be introduced. The level and degree of math used in the model is tailored to various grade levels; see Figures 2a and 2b for examples of the mathematics of brightness perception suitable for a short lesson or “stealth module” for algebra students.



The contrast between two surfaces is compared as a ratio of their luminances.

Figure 2a: From image to ratio: an example of using the Brightness Lab as a “stealth module” in elementary algebra class. Brightness perception is based on comparing the luminance values of two surfaces; the illuminant is not relevant.

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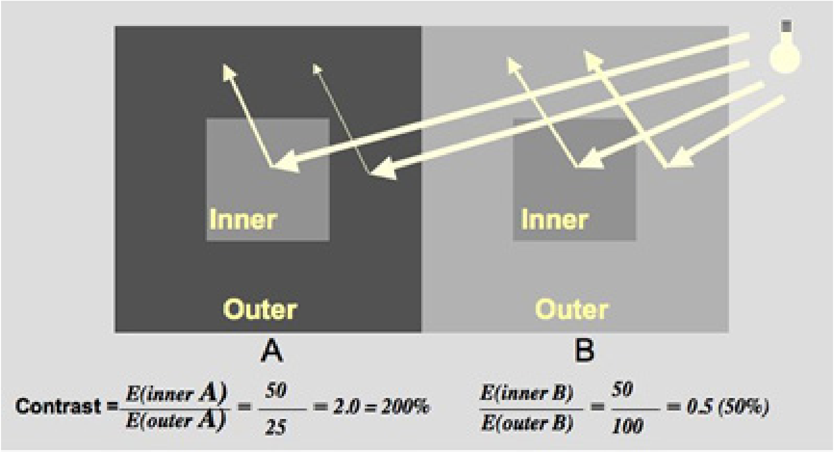
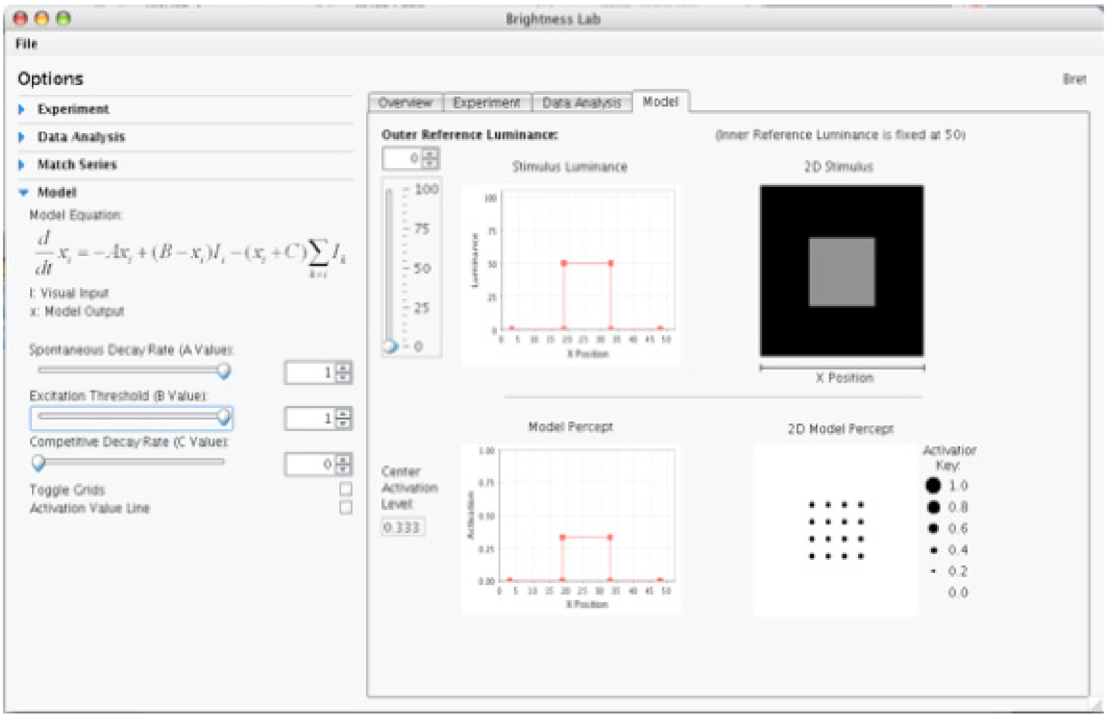
[12] See Grossberg (1982) for an overview of brightness perception and the neural network model that motivated this module.



Inner A area appears brighter than the Inner B area because of higher contrast.

Figure 2b: Brightness perception illusions are based on the brain's ability to calculate local contrasts and compare them across the visual field. Since Contrast A > Contrast B, it appears brighter.

There are two areas that call for a problem-solving approach to mathematics. First, integrated with use of the Brightness Lab software, a formal lab report helps students structure and assess their thinking as they collect experimental data about themselves, create visual displays of the quantitative data, and perform statistical analysis and interpretation. Second, a neural network model of brightness perception (see Figure 3) uses an ordinary differential equation to characterize the rate of change in neurons that leads to brightness perception.



Model Equation:

$$\frac{d}{dt}x_i = -Ax_i + (B - x_i)I_i - (x_i + C)\sum_{k \neq i} I_k$$

I: Visual Input
x: Model Output

Spontaneous Decay Rate (A Value): 1
Excitation Threshold (B Value): 1
Competitive Decay Rate (C Value): 0
Toggle Grids ☐
Activation Value Line ☐

Outer Reference Luminance: 0
(Inner Reference Luminance is fixed at 50)
Center Activation Level: 0.333

Figure 3: Software for student inquiry about brightness perception uses simulations based on a mass-action, shunting neural network. The equation represents the rate of change of neuronal activity.

Students are guided to the construction of the neural network model using an introduction to terminology, graphing symbols, and typical neural interactions of excitatory and inhibitory connections.

Directed experiments with simulations using software layers (controlled by the tabs on the top of the screen) are also provided. Parameters can be adjusted for simulations using drop down boxes or scroll bars on left of screen. The user can vary both the input as well as the process parameters of the network (the rate of passive decay of the signal, and maximum levels of excitation and inhibition in the system).

The structure of the software interaction is based on layers, or more concretely, on "tabs" within the program. In this way, the first layer is presented in the experiment and analysis tabs. A second layer is planned to take the student to an anatomy lesson (this part has been completed in print form only). The third layer takes the student to different aspects of modeling. Depending on the grade level in which the module is being used, different tabs or layers will be active, showing more (or less) information as appropriate to that particular grade. The software provides the interactivity and feedback needed to grasp a working knowledge of the brightness contrast effect. With deep understanding, the student will demonstrate transfer of knowledge to other contexts, such as art appreciation[13] (see Figure 4), graphic design, or night driving.

Figure 4: The bright-dark (*chiaroscuro*) technique achieves multiple aesthetic effects in *The Girl with the Pearl Earring* by Johannes Vermeer.

Feedback from teachers during the 2007 Summer Workshop has helped to refine the modules. For example, when secondary math teachers said, "Too much science.", the "For Math Class" Workbook was revised to focus on the review and application of linear regression analysis. Several responses to feedback that "The neural network is too abstract." are currently in progress. An exciting change is a modification of the software so the computer simulates the brightness matching game to tie the neural network model directly to the interactive experience of data collection experiment. Furthermore, an experiment history screen will help students (1) compare lines and nonlinear curves of best fit, (2) discuss how and why adjusting model parameters for passive decay, input-based excitation, and

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[13] For example, Asian "moon paintings" and the *chiaroscuro* (bright-dark) technique of Renaissance painters.

competitive interaction impacts the regression equations based on the computer simulations, and (3) compare these simulations with their personal data. To help the reader understand the derivation and structure of the neural network model of the perception of brightness contrast, the curriculum is currently being revised to include a more qualitative discussion about issues the visual system must resolve in order to process a wide range of input without loss of sensitivity. Finally, it is anticipated that presenting the quantitative model with reduced complexity (removing summation notation and subscripts) will help to focus attention on how the interaction of contrasting surfaces relates to the subjective experience of brightness perception.

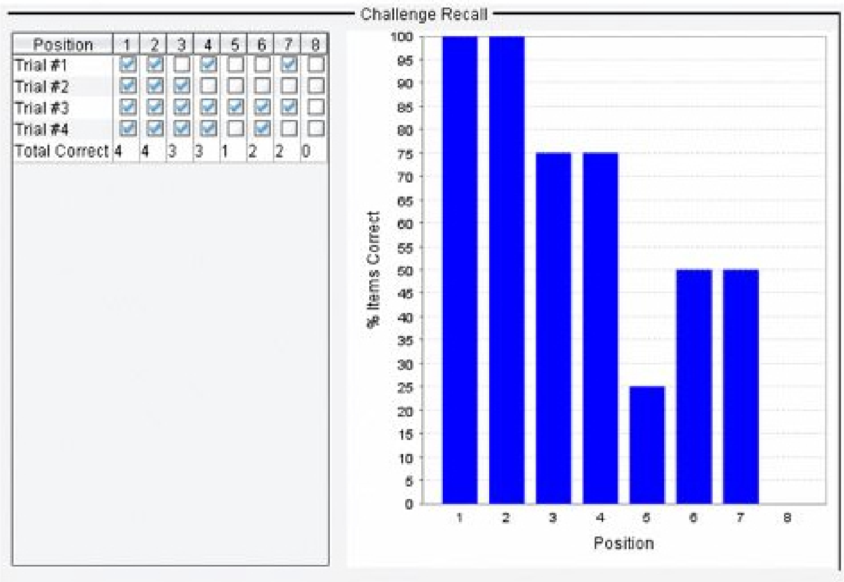
Sequence Learning

The Sequence Learning module integrates math and science curricula to study memory related to temporal order processing. Furthermore, the module is designed to develop study skills and introduce the scientific method via a formal lab report. Students collect experimental data on their own working memory span, perform an analysis thereof, and test the negative effect of distractions and the positive effect of explicit chunking on their memory span. There is also an opportunity to use an advanced mathematical model of sequence learning. Students discover that attention is a key factor in learning and that an individual’s memory capability varies and can be improved with effort.

After students have participated in short experiments and discussion aimed at showing how important yet fragile their working memory is, and the typical features of working memory performance (the first few and most recent items in a sequence are usually remembered best), they will be guided through the Sequence Learning software. The software module implements a set of psychophysical experiments that allow data to be collected to illustrate properties of working memory: list length/span (immediate serial order recall for lists of tokens such as digits, letters or pictures of varying lengths); list serial position performance (or error) curves showing better recall performance of items at the beginning and sometimes at the end of the list (at span and span+1); and list serial position performance curves with grouping. The software is easy to use with an intuitive interface, embedded instructions, and context sensitive help. The software supports the quantitative assessment of aspects of working memory that are explained in the background and theory document. Moreover, there is a seamless integration of the psychophysical experiment with the model simulation.

To begin the module, students are invited to consider their own experience and ask questions about possible mechanisms and models of sequence learning. In a motivating activity, students are confronted with a classic example of working (short-term) memory: remembering a phone number that you were just told. However, this type of memory is extremely fragile (i.e. easy to forget). For instance, if you hear the telephone number but accidentally trip on the way to dialing it, or if someone comes up to you and asks for directions immediately after hearing it, then you may not be able to dial it after you stand up again or answer the person's question; being distracted can greatly diminish your ability to hold things in working memory. In contrast, even if you are distracted, you can still recite your own name or your own telephone number when you need to. This sort of information is more stable and can be remembered virtually whenever you want; it is recalled from long-term memory. A natural question that arises for the students is: What properties of our working memory enable us to keep short sequences of events "in our minds" for a few seconds, but also allow us to learn particular, important sequences in a more stable way?

Module activities in the class include consideration of the issue: why can't we store arbitrarily long sequences in working memory? The question of why is there a natural upper bound on how many items can be stored at the same time[14] is explored in the software component for span testing. Students perform exercises where they generate the primacy effect where the initial items in a list are remembered better than later items (see Figure 5). The primacy effect is the first part of the common inverted-U performance profile related to serial position during free recall of the temporal order of list items. Students learn that this limitation reflects how the specific neural activities related to item-and-order memory change when new items come in. However, with longer lists there is also a recency effect where the last items in a list are remembered better than pervious ones. The recency effect completes the inverted-U performance profile and implies that that the items do not get stored with a primacy gradient all the time. Why is this? To have a long-term memory that retains a true representation of order information, we can only store relatively short lists in working memory at any given time. To be established in long-term memory, the short lists must typically be rehearsed. Longer lists in working memory would cause an inverted-U that would be transferred to long-term memory. Therefore, working memory and long-term memory are specialized such that they complement each other to provide rapid new learning along with stable old learning. Students are encouraged to develop these conceptual models of how our brains may be storing sequences of information in a working memory. One important constraint on how brains perform this task is that whenever we are actively thinking about an item in working memory, there is a specific location or network in the brain where that item is being represented. At least two possibilities exist for theories of how items in a sequence are stored within our working memory: positional models[15] and ordinal models[16].



Position	1	2	3	4	5	6	7	8
Trial #1	☑	☑	☐	☑	☐	☐	☑	☐
Trial #2	☑	☑	☑	☐	☐	☐	☐	☐
Trial #3	☑	☑	☑	☑	☑	☑	☑	☐
Trial #4	☑	☑	☑	☑	☐	☑	☐	☐
Total Correct	4	4	3	3	1	2	2	0

Figure 5: This visual display of psychometric data shows a clear primacy effect.

Students are guided through the construction of the neural network model using an introduction to terminology, graphing symbols, and typical neural interactions of feed-forward and feedback excitatory and inhibitory connections. Directed experiments with simulations using the model layer are provided

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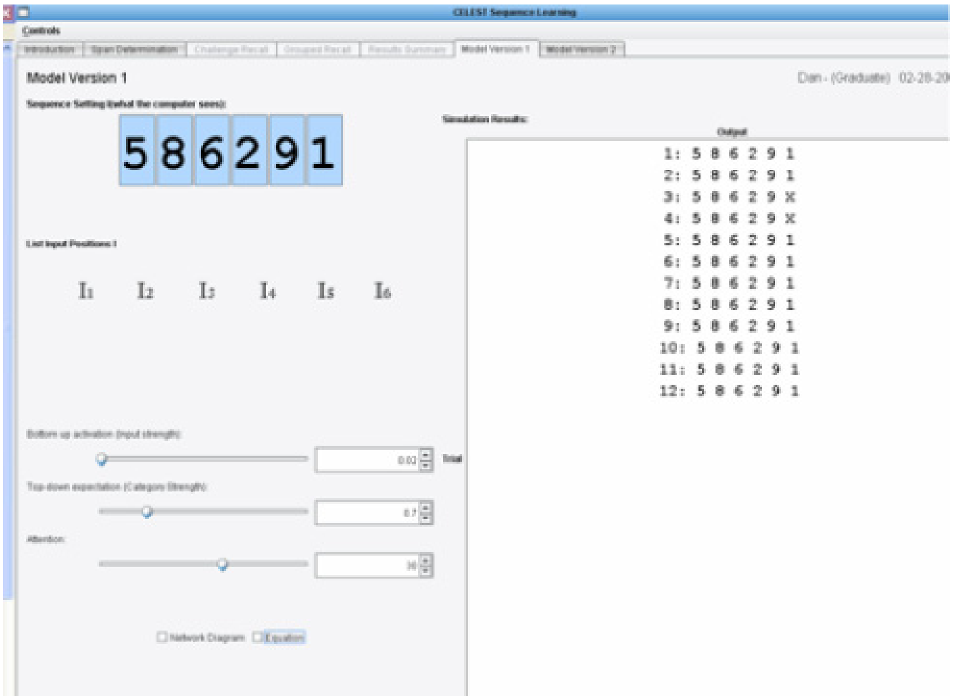
[14] For instance, Miller's limit of 7+/-2 and Cowan's limit of 4+/-1.

[15] In positional models, working memory is divided into locations (slots) whose relative positions represent the order of the items they are representing in the sequence. Under this model, new information could either go to the next available position at the end of the queue or take the initial position and push all of the existing information to subsequent positions.

[16] In ordinal models, such as competitive queuing, each item activates a single representation regardless of where in a sequence of inputs it occurs and its relative activity stores its position (i.e. the most active item indicates it is first, the second most active item is second, etc.).

on two levels. Level 1 is a conceptual use of the model, and simulations are comprised of the manipulation of three parameters (bottom-up activation, top-down expectation and attention) to see how these impact the ability of the model to learn a given sequence of digits (see Figure 6). Level 2 includes a complex network diagram, and the actual differential equations that support the outcomes of the model; 6 parameters are exposed. The Sequence Learning neural network model that is active in the software is an ordinal model called LISTPARSE (Laminar Integrated Storage of Temporal Patterns for Associative Retrieval, Sequencing and Execution[17]) which explains and quantitatively simulates cognitive data about immediate serial recall and free recall, including bowing of the serial position performance curves, error-type distributions, limited temporal extent for accurate recall, and word and list length effects.



Sequence Setting (what the computer sees): 5 8 6 2 9 1

Bottom up activation (input strength): 0.02

Top-down expectation (Category Strength): 0.7

Attention: 36

Simulation Results:

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Output
 1: 5 8 6 2 9 1
 2: 5 8 6 2 9 1
 3: 5 8 6 2 9 X
 4: 5 8 6 2 9 X
 5: 5 8 6 2 9 1
 6: 5 8 6 2 9 1
 7: 5 8 6 2 9 1
 8: 5 8 6 2 9 1
 9: 5 8 6 2 9 1
10: 5 8 6 2 9 1
11: 5 8 6 2 9 1
12: 5 8 6 2 9 1
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Figure 6: Software support for inquiry using a neural network simulation of sequence learning.

A valuable transfer of the lessons of this module is an application of the knowledge of the primacy/recency effects by both teachers and students for improved pedagogy and learning. To improve educational effectiveness over a given duration, activities should be segmented to short time-frames to maximize the number of primacy/recency events and thereby allow different learning objectives to enjoy the enhanced learning structure. In addition, if curriculum content is randomly practiced, there will be more effective long-term learning compared with routine, blocked drill because different items would enjoy the boost provided by primacy/recency positioning.

Temporal order processing also occurs with action sequences, such as pitching or hitting a baseball, playing a musical instrument, typing, or dancing. At first, you have to focus on each individual movement in the sequence and performance is irregular, but eventually you can perform an entire group of movements (or motor sequences) smoothly together. Were it not for working memories that enable us to learn these "sequence chunks", we would have to spend the whole day rehearsing the

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[17] Grossberg & Pearson (in press). The classroom presentation of the model builds on an earlier, simpler form: the STORE model (Bradski et al. 1994).

simplest activities, so as not to forget them; e.g., tying your shoes, brushing your teeth. Having a working memory that can allow chunks to be learned enables us to focus our attention on more interesting aspects of life, and is a crucial foundation for society, culture, and creativity. We are currently working with CELEST partners at Brandeis University to implement research on a stroke-imitation task[18] into the module. In this way, the user of the module will be presented with both cognitive and motor tasks that illustrate the properties of sequence learning.

Associative Learning

Associative learning is a basic form of animal and human cognition; adaptive-timing is a basic form of associative learning. We can easily recognize that most human brain activity and behavior require precise timing: for example, sleep, perception, speech, writing, walking, running, playing sports and video games of all types; you can think of several more examples. The ability to learn temporal conditioning is a critical survival competence in normal adaptive behavior because it enables the learning of which earlier events predict later consequences, as well as which event combinations are not causative. In this way, the individual can make the optimal choices for successful, adaptive behavior.

This module explores two conditioning paradigms for adaptive-timing as representative of procedural and declarative memory, namely, delay and trace conditioning. The learning measured is the association of a heretofore neutral event, such as a tone or a light, with an emotionally-charged, reflex-inducing event, such as a puff of air to the eye or a shock to some part of the body. The first event is called the conditioned stimulus (CS); the second is the unconditioned stimulus (US). Delay conditioning is said to occur when the stimulus events have temporal overlap and coterminate so that the subject associates concurrent sensations and learns to make an adaptive, conditioned response (CR) in anticipation of the US. Trace conditioning involves a temporal gap between the CS offset and the US onset such that a memory trace is required to make a successful CR.

In the first level of the module, students begin with an experimental, interactive task that simulates aversive conditioning: click the mouse before a red disc (the US) appears. There are multiple training schedules of the appearance of the red disc: (1) a random appearance, (2) at a fixed time interval as an event that follows an initial blue disc (CS), and (3) a probabilistic appearance at a fixed interval after the CS terminates. In the second level, the visual display of results for each schedule support a discussion of conditioning, adaptive timing and the learning curve; students discover their own learning curve in the fixed schedule trace paradigm. Performance data is presented in multiple formats to show their differences: bar graphs, scatter plots, line graphs, and, to begin a higher level of analysis, linear regression. We are currently enhancing the software to include nonlinear models of the learning curve that may have a better fit to the data.

The third level of the module uses the study of eye-blink conditioning to develop a deeper understanding of the types of memory. The eyeblink response, measured by eyelid movement in rats, cats, monkeys and humans, and the movement of the nictitating membrane (NM) that covers the eye like an eyelid in rabbits, has been extensively studied because it has given excellent parametric behavioral, neurophysiological and anatomical information about the learning and memory processes related to associative conditioning. There is a complete model layer based on published research[19] that simulates the NM response as measured by the timing and amplitude of its movement and the

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[18] Agam et al. (2005).

[19] Fiala et al. (1996) develop a model based on cellular neurophysiology.

cerebellar response that supports the behavior. The software simulation is comprised a multi-dimensional GUI interface with adjustable parameters such as the conditioning paradigm, the onset/offset times of CS and US, the learning and extinction rates, and number of Purkinje cells in the network (see Figure 7).

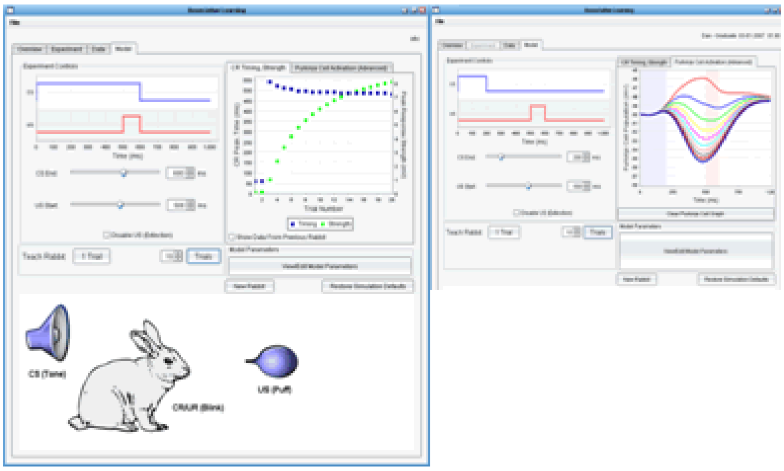

Figure 7: GUI support for inquiry about behavioral and cellular responses using a neural network simulation of adaptive timing.

There are currently three phases in this level, each exposing the model and the simulation results in greater detail. Similar to the effort in Brightness lab, work is underway to provide a simulation of the experimental task related to the blue and red discs performed by the students in this module so there will be a tight coupling of the neural network to student experience. We have found this approach effective in Sequence Learning.

Discussion

CELEST curriculum promotes several types of interaction: between students and their peers, students and teacher, students and computer, and students with themselves. Student activities are designed to provide formative feedback as learning progresses. Summative feedback activities are designed to test students' content-knowledge, and provide teachers and curriculum developers with information to improve methods and materials.

Each of the modules contains a variety of models[20] that range from qualitative, motivating representations of experience and anatomy, through data collection and analysis, to neural modeling. In order to properly scaffold new knowledge and maximize learning from the modules, the approach is to first find out what students know about the content, then present models about perception, cognition, emotion and behavior in pictures, diagrams and words. These representations can reach learners with less developed mathematical skills. As requisite quantitative skills mature, the learner can be exposed to mathematical models; in fact, the modules can be used to teach and reinforce various mathematical concepts and procedures at many instructional levels.

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[20] Petrosino (2003) outlines a framework of models ranging from qualitative to quantitative models; that is, from physical, representations that are similar to reality to increasingly abstract, mathematical representations in which algebraic variables serve to represent measurable dimensions of reality. Indeed, it is the use of quantitative models that is the earmark of modern science and scientific thinking.

A major goal of the CELEST curriculum is to support both an intuitive, qualitative understanding of modeling, as well as the ability to create, interpret, use, and critique mathematical and computer models[21]. Figure 8 shows the CELEST modeling process that integrates thinking about design principles, data, analysis, and application. A firm grounding in method is essential to any success for modelers. Thus, the modules develop notions of model design, limitations, simulations, experimentation, and change. How might models be created? How is experimentation and hypothesis testing done using simulations based on mathematical models? Which simulations versions should be compared and contrasted? How are parameters systematically changed by the experimenter to answer or form questions? How do models provide an opportunity for collaboration among scientists? The underlying success of this aspect of the curriculum is the development of critical thinking (hypothesis making and testing), and a deeper understanding of mathematics.

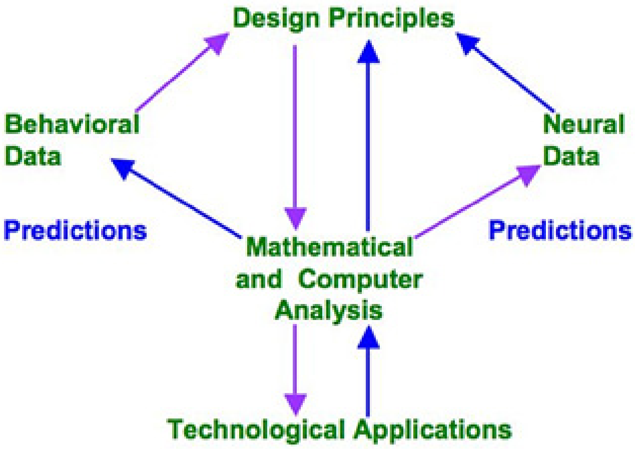

Figure 8: The CELEST modeling cycle is guided by thinking about thinking.

How has the curriculum been received in the classroom? We have found that the CELEST curriculum is intrinsically motivating to students and provides an authentic experience of scientific and personal inquiry. A 6th grade teacher reported her students' experience with an early version of the Sequence Learning module in 2006:

> *Interpreting the data was both exciting and practical in their eyes. I decided to use this module right before their first Biology test so that they can use the knowledge from their results to help them study. I found that to be greatly successful! The average grade for 47 students was a B! Most of the girls were bubbling over with how helpful it was to learn about their working memory at this point in time and were quite sincere in their appreciation. It was also a nice introduction to a formal lab report.*

Action research projects[22] are planned and anticipated to help improve classroom practice. Additionally where possible, external validation studies will be conducted to determine whether CELEST curriculum and pedagogy positively influence student perceptions and learning processes related to knowledge acquisition, specific process skills, and attitudes.[23] Beyond support for content knowledge in science and mathematics, the study of how cognitive, emotional and behavioral learning

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[21] See Hestenes (1996) for a discussion of how to make mathematical modeling a focus of science instruction.

[22] Mcniff (2003) reviews the important place of action research in educational improvement programs.

[23] Resources include the CELEST external evaluator, American Statistical Association (2007), The National Council on Measurement in Education (2008), and Bond & Fox (2007).

interact to develop consciousness is also expected to help to develop a sense of conscience. A critical task is to identify or develop assessment instruments, experimental designs, and schedules. A sample study might be to evaluate if data provide evidence of significant differences between students who did an applied statistics assignment involving CELEST Brightness Lab curriculum and those who did an applied statistics assignment that did not involve CELEST curriculum.

An additional focus will be on the degree to which teachers use the curriculum and continue post-workshop collaboration through a CELEST online community. A prototype web resource is currently available to registered users who would like to interact and share questions, implementation strategies, content, and results. We look forward to teachers conducting CELEST curriculum workshops for other teachers, and developing grant proposals for further implementation. In the meantime, the CELEST team is vigorously updating the curriculum based on continued feedback, requirements for specialized audiences, and interaction design principles.

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Reference List

Agam Y, Bullock D, Sekuler R (2005). Imitating unfamiliar sequences of connected linear motions. Journal of Neurophysiology 94, 2832-2843.

American Statistical Association (2007). Using statistics effectively in mathematics education research: A report from a series of workshops organized by the American Statistical Association with funding from the National Science Foundation. Available: http://www.amstat.org/research_grants/pdfs/SMERReport.pdf

Bond TG, Fox CM (2007). Applying the Rasch Model: Fundamental measurement in the human sciences. 2nd Ed. Lawrence Erlbaum.

Bradski G, Carpenter GA, Grossberg, S (1994). STORE working memory networks for storage and recall of arbitrary temporal sequences. Biological Cybernetics, 71, 469-480.

Bransford JD, Brown AL, Cocking RC, eds. (2000). How People Learn: Brain, Mind, Experience, and School. National Academy Press: Washington, D.C..

Fiala JC, Grossberg S, Bullock D (1996). Metabotropic glutamate receptor activation in cerebellar Purkinje cells as substrate for adaptive timing of the classically conditioned eye blink response. Journal of Neuroscience, 16, 3760-3774.

Grossberg S (1982). Why do cells compete? Some examples from visual perception. The UMAP Journal, 3, 103-121. Available: http://www.cns.bu.edu/Profiles/Grossberg/Gro1982UMAPJ.pdf

Grossberg S (2005). CELEST - The Center of Excellence for Learning in Education, Science, and Technology. Brains, Minds and Media, Vol.1, bmm153 (urn:nbn:de:0009-3-1535). Available: http://www.brains-minds-media.org/archive/153/.

Grossberg S, Pearson LR (2008). Laminar cortical dynamics of cognitive and motor working memory, sequence learning and performance: Toward a unified theory of how the cerebral cortex works. Psychological Review, in press.

Hestenes D (1996), Modeling Methodology for Physics Teachers. In E. Redish & J. Rigden (Eds.) The changing role of the physics department in modern universities, American Institute of Physics Part II. p. 935-957.

Kulak D, Guiney E (2000). Use Cases: Requirements in Context. ACM Press: N.Y., N.Y..

Mcniff J (2003). You and Your Action Research Project. Routledge Falmer Publishing: Oxford, U.K..

National Council on Measurement in Education (2008) at http://www.ncme.org/pubs/items.cfm.

Petrosino A (2003). Commentary: A framework for supporting learning and teaching about mathematical and scientific models. Contemporary Issues in Technology and Teacher Education [Online serial], 3(3). Available: http://www.citejournal.org/vol3/iss3/mathematics/article1.cfm.