Activities and findings:

Research and Education Activities:

The activities under this award have proceeded in a number of interacting laboratories and working groups. Below are summaries of the activities of the major subgroups. Major co-PI collaborations are indicated in parentheses of subheadings. Many other less formal collaborative efforts occurred with personnel other than the PIs and among all PIs during weekly seminars.

Gallistel Laboratory (including collaboration with Merriam)

The idea behind this project was to develop behavioral screens to detect mutants that remember simple quantities like duration and distance wrong, that is, they remember a duration or they remember a distance but the quantity they remember is not the one that they originally experienced. Another way to think about this kind of screen is that it looks for calibration errors in memory. The function of memory is to carry information forward in time. When the information in question is quantitative information, like duration and distance, then the function is to deliver back when 'read' the same quantity that was 'written' to memory in the first place. Memory is miscalibrated if the quantity delivered upon reading differs systematically from the quantity originally written.

We began by trying to teach Drosophila melanogaster simple duration and distance memory tasks, but we were unable to get any sort of reliable behavior from these subjects.

After months of fruitless effort with the flies, we shifted to mice. We constructed a large apparatus for the simultaneous testing of both duration and distance memory in mice. The mice proved much more behaviorally tractable. We have done several experiments on systematic error in their duration memory and are working on a new system for measuring their distance memory.
Gelman Laboratory (including collaboration with Gallistel, Kellman)

A major goal of the project was to study learning as it occurs in complex environments, where the data have rich and potentially confusing structures. A fundamental assumption of the LIS group is that both perceptual and conceptual learning is most likely to be fostered if offered inputs represent many multiple examples of the principles of the target learning as opposed to multiple trials with the same examples. To achieve an account of learning for understanding, one also must know what learners bring to learning settings, how these are interpreted, how to encourage attention to relevant aspects of the offered data, and movement onto what I have Relevant Learning Paths. Gelman and her collaborations (including PI’s in the program as well as students and postdoctoral fellows) addressed these by focusing on topics in mathematics and science.

Kellman Laboratory (including collaboration with Russell, Gelman)

A major goal of the funded work was to examine the applicability of perceptual learning concepts to mathematics and science learning. These concepts had previously been applied with excellent results in aviation training (Kellman & Kaiser, 1994), especially in instrument flying curriculum, perhaps the most difficult and conceptual part of flight training (Kellman, Stratechuk & Hampton, 1999). With Tate Kubose, Wise and Gelman, we studied PL effects on mapping across multiple representations (graphs, equations, and word problems) of linear functions.

With Shaun Hussein, Arlene Russell and Orville Chapman, we studied perceptual learning in organic chemistry at the university level. Three elusive parts of chemistry teaching are developing students’ intuitions about 1) molecular structure, including bond numbers, angles, and hybridization, 2) the meaning of chemical notation, and 3) the three-dimensional (3-D) configurations of molecules represented in notation. These are linked problems, because the notational formats used to represent molecular structure are usually impoverished. Knowing 3-D structure requires combining the information in the notation with intuitions about 3-D structure and constraints. To address these problems, we developed two perceptual learning modules. One presented multiple short trials on which subjects were shown rotating, 3-D ball-and-stick models and had to judge the angle of a highlighted bond, the number of atoms bonding to a highlighted atom, or the hybridization of the molecule. The other module involved trials of structure mapping between ‘letter-and-line’ molecular notation and rotating 3-D molecules, where some of the rotating molecules included the correct atoms but had physically impossible structures. These modules comprised short interventions that could be
done in about 30 minutes each. Silva & Kellman (1999; in preparation) studied the 'algebra-geometry connection.' This effort involved transformations of functions and the mapping between graphs and equations. For example, how does the graph of \( Y = \sin X \) change if the equation is changed to \( Y = \sin 6X \), or \( Y = \sin (-X) \) or \( Y = 3 \times \sin X \)? Most students initially try to solve such problems by substituting values in for \( X \) and reasoning their way to the correct graph. In our learning module, we presented graphs (e.g., \( Y = \sin (-2X) \)) and students made a speeded, forced-choice of which of three equations matched the graph. In a series of experiments, students either did active classification or received passive exposure to these mappings, and different kinds of feedback were given. In all cases, students performed structure mapping tasks involving transformations involving two families of functions (e.g., \( \sin \) and \( \log \)) and were tested on: new examples of the same families, new examples from new function families, and complicated compound functions (e.g., \( Y = (-3 \sin X) \times (\log 4X) \)).

Gelman, Kellman, and John Whalen did an encouraging pilot study of perceptual learning in rational numbers, which has been followed up by Christina Schofield in Kellman’s laboratory. In parallel to these several lines of research, we have pursued basic research and modeling in Kellman’s laboratory. Kellman, Burke & Hummel (1999; Hummel & Kellman, 1998) initiated studies of the problem of learning of abstract invariants. The problem is of crucial importance. Almost all models of perceptual learning depend on inputs that are concrete, i.e., particular activations of cortical cells sensitive to specific edge orientations in specific locations. Much of human learning is abstract, i.e., learning to correctly apply the label 'square' to new instances. The current situation is that a huge gap separates existing models from the most interesting learning capabilities of humans.

Stabler Laboratory (including collaboration with Taylor)

In this project we undertook an exploration of the following basic ideas:

* Language learners identify regularities when the cost of remembering the regularity is offset by the benefits in representing the language. (Similar to 'Minimal Description Length (MDL) theories': on appropriate size metrics, the language learner aims to minimize the size of the grammar and the encoding of what is heard.)

* Language changes in part through ``transmission errors," cases where the child adopts a grammar that is unlike the parents'. Given 1, some of these transmission errors will be
errors in favor of simpler representations. (As in MDL approaches, the child will err in favor of more succinct grammars and encodings.)

* Supposing that linguistic theory is at least roughly on the right track, then the appropriate size metrics are those given by recent theories. (But when calculating sizes, do not count the same piece of information repeatedly!)

These general ideas were explored formally, yielding parsability and learnability results, and we also developed particular analyses of prominent constructions in English (with particular attention to the auxiliary verb system) and in Hungarian.

Russell and Chapman (including collaboration with Kellman, Gelman)

(1) Chemists have developed advanced written notations to convey the structure of molecules. Although the symbolism represents only the connectivity of the atoms, these impoverished representations imply the specific geometry of the molecule. Representations, which was developed under this grant, trains students to relate the notation of the impoverished drawing with the richness of the three dimensional structure of the molecule. Random presentation of a variety of impoverished drawings, typical of textbooks, are compared with three-dimensional models of rotating molecules drawn using advanced lighting and rendering techniques. The models may be correct or may include logical but incorrect interpretations of the drawing. Students identify the accuracy of the model and receive corrective feedback if appropriate.

(2) Analysis tools were developed for 3D Angles, an interactive tutorial which teaches the relationship between three different concepts used to imply geometrical structure in molecules: the bond angle (a geometric construct), the hybridization of the central atom (a quantum mechanical construct), and the coordination number (the number of other atoms bonded to the central atom).

Like Representations, 3D Angles uses pattern recognition principles introduced through rapid repeated exposure to three concepts to teach students to intuitively associate the three terms together in order to be able to correctly recognize the molecular structure from limited information.
Findings:

Gallistel Laboratory

MAJOR ACCOMPLISHMENTS

- With the pilot data obtained from this project, CRG secured a grant from NIMH to further develop the system (MH63866 Automated Testing for Mice that Remember Wrong)

- Also, building on the results from the LIS work, CRG in collaboration with another psychologist, Alan Leslie, and a geneticist, Jay Tischfield, an internal grant from Rutgers University ('The genetic basis of cognitive function: An Interdisciplinary Laboratory of Cognitive Genetics')

- Demonstrated that the peak procedure works in mice, generating data comparable in every respect to those obtained from rats, pigeons and humans, including the systematic scalar error, which helped inspire this approach to memory screening in the first place.

- Showed that the systematic error is the result of asymmetric decision criteria rather than a miscalibrated memory.

- Showed that the scalar variability in duration memory is primarily due to trial-to-trial variation in timing rather than to memory noise.

- Began development of an ingenious new approach to an automated system for measuring distance memory, which may make possible the automation of many other kinds of behavioral tests.

- Initiated collaboration with Clever Sys, Inc on the development of a highly automated turn-key system for screening the behavior of genetically and pharmacologically altered mice.

Gelman Laboratory

With Gallistel, Cordes (Student), Whalen and Hurewitz (Postdocs) we have demonstrated that humans share with animals a non-verbal counting mechanism, and that these are represented as separable ordered quantities. The data in animals and humans share a common statistical signature – scalar variability. This contrasts with the signature obtained when adults are allowed to count.
I (with collaborators) have completed empirical and theoretical papers on the question of how to characterize supporting learning environments, both for early, relatively easy cognitive development, and later learnings that are hard. The research papers include studies that reveal preschoolers’ of implicit knowledge of arithmetic principles like associativity; the relationship between energy sources or forces and the movements of animate and inanimate objects; the kinds of math concepts elementary school children find easy as opposed to hard to master; the effect of embedding organized, conceptually based learning materials in classrooms (preschool daily activities, Grade 9 ESL, and Grade 9 Algebra). The latter includes Denise Pinon’s dissertation, which is a controlled study of the effects of using two different formats to teach the multiplication of polynomials. Results also indicate that preschoolers can benefit from opportunities to do and learn about science. We also have been able to show that notebooks can become a tool for assessing learning about both science and English in an ESL class. It remains for us to crack the problem of moving individuals from treating rational numbers as natural numbers. More about this below.

These results are part of a programmatic effort to determine when numerical representations are read 'automatically', just as are words by literate readers; the development of a bi-directional mapping between the non-verbal and verbal. They also have led us to a renewed interest in the way beginning speakers of a language come to understand the count words, mathematical terms like ‘add’, ‘subtract’, ‘estimate’, and so on. They also have encouraged us to embed a great variety of measuring tools in our preschool science program (Preschool Pathways to Science - PrePS©. (See Below).

Major Accomplishments:

* The LIS grant provided key additional funding for a collaborative effort with UCLA Child Care to develop a comprehensive way to embed relevant science and math learning experiences into regular, everyday activities. The design of these was based on the findings regarding early cognitive competence and the theory about relevant learning experiences that is foundational to the LIS grant. Therefore, the focus is on ways to provide multiple examples of core scientific concepts and the related language and tools of science. The UCLA teachers and members of the Gelman lab are repeatedly asked to give workshops on the program. This has led Gelman’s lab at Rutgers to agree to start PrePS©, Preschool pathways to science in 2 sites in the New Brunswick, NJ area.

* Research on the role of multiple formats for learning mathematics

* Research on the conceptual constraints on use of information about forces of energy
* Research on nonverbal arithmetic – with Gallistel, Cordes, Whalen, PhD and Hurewitz, PhD

* Research on the acquisition of automatic reading of mathematics

* Research on the acquisition of knowledge about rational numbers

* Research on early learning about scientific content, language and its tools.

* Developed research tools for determining whether learners attend to and start to acquire knowledge about relevant inputs. For example, how to use Scientist’s Notebooks (suitable for a given age) to track whether learning is taking place.

Kellman Laboratory

Results of the experiments on mapping across multiple representations showed reliable improvements on speed and accuracy in mapping of all pairs in this triad. Moreover, remote transfer to tasks where students generated equations or graphs from the other representations showed significant improvement. This basic finding, which occurred after two 30-minute learning sessions, is highly encouraging and will be followed up and extended in ongoing research. Even the very brief chemistry learning modules led to substantial improvements on the classification tasks. Most important, students showed reliable improvements, relative to a control group, on relevant sections of the course final exam (Hussain, Russell & Kellman, in preparation; Russell & Kellman, 1999).

In the Silva & Kellman work on the algebra-geometry connection, under an hour of learning produced clear gains in mapping graphs onto equations. New instances in the function families were just as good as instances that had been used in the learning phase. In several learning conditions, students strongly transferred their learning to new functions families, indicating that they had extracted the abstract structures of the transformations. Several basic findings in this research form the bases for questions in ongoing research, including the roles of active vs. passive exposure in discovery and fluency, and the role of feedback.

Work under the LIS award clearly demonstrated the value of perceptual learning concepts in math and science learning, and has stimulated empirical studies and modeling of the learning of abstract invariants in human perceptual learning. All of these efforts have uncovered a host of issues requiring further research. Many of these are being explored in subsequent, funded research.

On the modeling side, Kellman, Burke & Hummel (1999) put forth a
proposal of the style of modeling that might bridge the gap between current concrete models of perceptual learning and the abstract learning that humans display. They constructed a model that does early relational recoding of inputs. It can learn planar shape terms from a few examples and shows generalization characteristic of human learners. From a very small number of learning examples, the model shows invariance over orientation, scale, and small distortions. Both modeling efforts and basic empirical research on the scope and limits of human learning are continuing. The requirements for extracting abstract relationships in perceptual learning are poorly addressed by most current research, clearly important in human perceptual learning, and highly relevant to the applications of perceptual learning techniques to learning and education.

Major Accomplishments:
- Perceptual Learning Techniques. Completed proof of concept studies indicating the value of perceptual learning techniques in mathematics and science learning
- Active vs. Passive Learning. Showed that passive learning trials may be just as effective in perceptual learning contexts as active ones
- Role of Feedback. Showed that perceptual learning in mathematics is sensitive to the type of feedback used
- Follow-on Research. Generated pilot data leading to recent NSF ROLE Grant 'Perceptual Learning in Mathematics and Science: Structure Discovery, Fluency, and Integration' (with C. Massey), 2003 - 2006.
- Modeling on Abstract Learning. Proposed a model of how early relational recoding of visual inputs might lead to abstract perceptual learning

Stabler Laboratory

Major accomplishments include:

* defined a class of grammars for study (Stabler 1997)

* established that languages with 5 counting dependencies are included in the class (Stabler 1997,1999), and that certain subsets of the class are learnable (Stabler 1998)

* established that the class is identical to one already known to be generated by MC-TAGs and MCFGs (Harkema)

* established these languages efficiently parsable (Harkema)
* established learnability of a certain class of grammars from strings
together with 'meaning recipes' (Fulop)

* provided analyses of English auxiliary verbs (Becker) and
Hungarian verbal constructions (Szalai, Stabler), with attention
to learnability

Russell and Chapman Laboratory

Major products include:

1) Representations:
http://www.molsce.ucla.edu/pub/explorations.html#Representations

(2) 3D Angles:
http://www.molsce.ucla.edu/pub/explorations.html#3D%20Angles

Training and Development:

Training and Facilitation

This project involved a large number of students in a variety of
disciplines (including psychology, linguistics, chemistry and
biology). Numerous doctoral theses were completed in connection with
the funded research. Experience in the project helped pave the way
for many students' further educational or professional pursuits.
These training, development, and facilitation effects are detailed in
this section.

Gallistel Laboratory

One graduate student, Belinda Tam, and three undergraduates, Eric
Chang, Omar Mahmood, and Jeffrey Gold participated in the project.
All three undergraduates have gone on to do graduate work in
psychology (Mahmood), neuroscience (Chang), or medicine (Gold). Tam is
completing her MD/PhD at UCLA but switched to another project when CRG
left UCLA.

Development and Facilitation:
The project is likely to eventuate in major advances in behavioral
screening technology, which is going to be of the first importance in
harvesting the fruits of the gene mapping effort, that is, in
identifying the functions of the many genes of unknown function
expressed only in the CNS. It is bringing behavioral testing
technology into the industrial setting.

Gelman Laboratory

Students who Obtained PhD During the Period of the Grant

*Barbara Gonzales – Staff to LIS Project
Assistant Professor – Education; Science Learning at Northridge, Cal
State. 'Gonzalez, Barbara' <bgonzalez@Exchange.FULLERTON.EDU>
Recent recipient of NSF Career Grant
*Wendy Francis – PhD at UCLA
Assistant Professor, Department of Psychology, University of Texas, El
Paso; Co-Author on chapter on notebooks as a way to follow science and
English learning in 9th Grade ESL Students – LA
*Laura Romo – PhD and Postdoc from UCLA
Assistant Professor – Medical School, University of Texas, MB;
Co-Author on chapter on notebooks as a way to follow science and
English learning in 9th Grade ESL Students – LA
*Denise Pinon, PhD -- Dissertation was a collaboration between RG and
Mark Govatis (Head Mathematics Teacher at Crossroads High School).
Now in a major job in the Austin School District’s Elementary
Assessment Division.
*Earl Williams, PhD – - Dissertation was co-sponsored by Kellman.
-- is interviewing for jobs that focus on Man-machine interactions.

*Tate Kubose, PhD – In addition to his dissertation work with Holyoak,
worked with Kellman and Gelman on, multiple representations and own
course on the novice-expert distinction; now doing a post-doc at
Columbia University.

Current Graduate Students

*Beth Lavin – Grad Student at UCLA, transferred to Rutgers; PhD
expected June 03
-research relates knowledge of the biology of kinship to related
cultural assumptions
-in addition to her thesis research, she heavily involved in
introducing PrePS© in the New Brunswick, NJ area. A test as to how
easily the program is exportable.
-Wants a position that will allow her to expand the use of PrePS©
*Sara Cordes – see below
*Osnat Zur – Research area focused on preschooler’s mathematical
knowledge and ability to learn analogies based on the common structure
of spoken word problems. Won a UCLA Dissertation Fellowship; in
charge of the CogDev and LIS involvement in PrePS®

*Kevin Reed:  On University Fellowship at Rutgers.  Research on learning about the language of number and quantity in English and Chinese.  (He speaks, reads and writes Mandarin) and has live in Taiwan.  Chinese has the characteristic of being less ambiguous in descriptions of number and quantity. Brings a double major in Philosophy and Psychology to his projects).

*Jennifer Cooper:  On CogSci training grant at Rutgers. Is working on what young children are learning about the meaning of the terms they start to use when offered relevant inputs for science. She is especially interested in the development of prowess for problem-solving. (brings backgrounds in psychology and computer science to her agenda).

Undergraduates

*Sara Cordes – UCLA Undergrad in Applied Math and Psych  
  In PhD Program in Cognitive Science and Psychology at Rutgers  
  Won an NSF Fellowship to continue work funded on LIS on nonverbal counting and arithmetic.

*Stephanie Reich – Undergrad at UCLA and staff on LIS  
  Grad Student in Psychology at Vanderbilt  
  Area: Public Policy

*Girlie Delacrux – Staff for LIS  
  Moved to work in Stigler Lab; then to CRESST at UCLA  
  Now applying to UCLA’s Grad School of Education in the Psychological Studies in Education PhD program.

Development and Facilitation:
1. See above.
2. In addition, I am frequently asked to give talks about setting up preschool learning environments. I also am a member of the NJ State committee that is developing standards in math and science for daycare and preschool sites.
3. I am a collaborator on a Center for Teaching and Learning proposal, going from Rutgers.
5. Child Care Board, Department of Psychology, Rutgers-New Brunswick
8. Graduate Coordinator for Cognitive Area – Rutgers Dept of Psychology.

Grants

modeling of domain-specific learning processes: The case of learning about fractions (Rational numbers). Strategic Resources and Opportunity Analysis Award. Rutgers University. $75,000 (Direct Costs). (This allows me to develop further my relations with Mathematicians (Goldin) and Computer Scientists in AI (Steinberg). The pilot work will form the basis of an interdisciplinary attack on the question of how to model conceptual learning.


Gelman, R. (Submitted Spring, 2002) Cognition and learning about mathematical concepts. Submitted to OERI. Requested $666,000 (TDC and IDC) for 3 years. Encouraged to re-apply.

Gelman, R. (to be submitted). A proposal for studying whether Dyscalculia can serve as a model for how to characterize learning disabilities. McDonnell Foundation. Will request $100,000.


I also will be submitting a proposal to NSF for renewed funding of my basic research.

Kellman Laboratory

* Ana Silva (Psychology) completed masters' thesis on perceptual learning in mathematics. She is now working as a preschool teacher.
* Christina Schofield (Psychology) completed masters' thesis on perceptual learning in rational numbers. She is now a third-year doctoral student at UCLA.
* Norma Chang worked as a research assistant on perceptual learning in mathematics. She is now a doctoral student in Psychology at Carnegie-Mellon U.
* Tate Kubose (Psychology) worked as a research assistant on perceptual learning and mapping across multiple representations. He is now a post-doc at Columbia U.
* Shaun Hussein (Chemistry and Cognitive Science) is now a medical student at Albert Einstein College of Medicine.
* Timothy Burke (Computer Science) is now a fulltime research assistant in Kellman's laboratory at UCLA.

Development and Facilitation: The funded research has contributed to collaborations with computer scientists Judea Pearl and Adnan Darwiche on the relations of
perceptual learning and decisionmaking, including optimization of
decision aids and modeling of abstract learning. This work is funded
through an MURI award 'An Integrated Decision Aid' from the Office of
Naval Research (approx. $4,000,000 from 2000 - 2005, shared among 6
investigators).

The LIS project directly paved the way for a recent award from the NSF
ROLE Program (with Co-PI Christine Massey of the University of
Pennsylvania). The award 'Perceptual Learning in Mathematics and
Science: Structure Discovery, Fluency, and Integration' is for
$1,600,000 between 2003 and 2006.

Russell and Chapman Laboratory

* Shaun Hussein (Chemistry and Cognitive Science) is now a medical
student at Albert Einstein College of Medicine.
* James Kliegl graduated from UCLA in 2000.

Development and Facilitation:
The engine for Representations is being used to develop similar
interactive tutorials for other areas of Chemistry in conjunction with
the NSF-funded FLASH project: NSF DUE 99-50320

3D-Angles forms the basis for two 'Calibrated Peer Review' writing
assignments that are available publicly and used by 100's of schools.
http://cpr.molsci.ucla.edu

Stabler Laboratory

*Misha Becker (Linguistics) now Assistant Professor, University of
North Carolina, Chapel Hill
*Sean Fulop (Linguistics) now Visiting Assistant Professor, University
of Chicago
*Temmy Szalai (Linguistics) now works for Nuance, a language software
company
*Gianluca Storto (Linguistics) expects to complete his Ph.D. at UCLA
in 2002
*Daniel Albro (Linguistics) expects to complete his Ph.D. at UCLA in
2002

Development and Facilitation:
This work also inspired work at the University of Potsdam (esp. the
Ph.D. thesis of Jens Michaelis), at the University of Tuebingen (by
Moennich, Cornell, Moraweitz), and at the University of Utrecht
(esp. the M.S. thesis of Willemijn Vermaat)
Outreach Activities:

Outreach activities have included the talks, papers, book chapters, websites, and curricula listed in other sections above. Moreover, several branches of this project included close collaborations with schools in the Los Angeles area, including Crossroads High School, the New Roads Schools, and University Elementary School (UCLA).

Journal Publications:

Book(s) of other one-time publication(s):
of Collection: Dupoux, E., "Cognition"

Other Specific Products:

Teaching aids

science: A guidebook. (Funding from the LIS Grant; Matching LIS fund from
UCLA; Start-up fund to RG at Rutgers)

PrePS©,. Draft of a preschool program to offer math and science
learning
opportunities. A penultimate ms. updated by K. Brenneman, should go
to
publishers during the year 2003.

Internet Dissemination:

http://visionsciences.psych.ucla.edu/ http://www.molsci.ucla.edu/pub/
explorations.html#Representations

Contributions:

Contributions within Discipline:

The project, multidisciplinary in conception and execution, has
contributed to basic knowledge and applications of that knowledge in a
variety of disciplines. Most of the implications are summarized in
the Findings section above. They include understanding of basic
mechanisms of learning at many levels, from genetics, to the
development of grammars, to the apprehension of structures by
mathematics students.

Contributions to Other Disciplines:

As indicated above, the project was inherently multidisciplinary, so
the implications flow in many directions. Details may be found in the
Findings section of this report.
Contributions to Education and Human Resources:

Our results have contributed to human resource development in at least two ways. One is the large number of students and collaborators at all levels who have added to and hopefully benefitted from the ideas in the funded research.

The second contribution involves the applications of our results to mathematics and science learning. These are new and still evolving, but they hold the promise of improving learning, overcoming characteristic difficulties, and improving access to math and science success for traditionally underrepresented groups.

Contributions to Resources for Science and Technology:

As some of the focus of this multifaceted project included learning in educational contexts, the findings and implications of much of the research, as described in several parts of the report, directly impact education.

Our research findings have paved the way for important follow-on projects on virtually every topic investigated under this LIS award.

Contributions Beyond Science and Engineering:

The contributions of work under this award extend beyond the specific research issues. Applications of perceptual learning technology, investigated in part of this project, will extend beyond science and mathematics learning to commercial and military applications, as well as to learning in other academic areas. Work related to the grammar of natural language has some relations to efforts to improve internet search engines. Test equipment developed for the learning genetics part of the project may have other important uses, as indicated above.