



**Mathematical Sciences:
discovery, connections, community**

Peter March

Director, Division of Mathematical Sciences

National EPSCoR Meeting

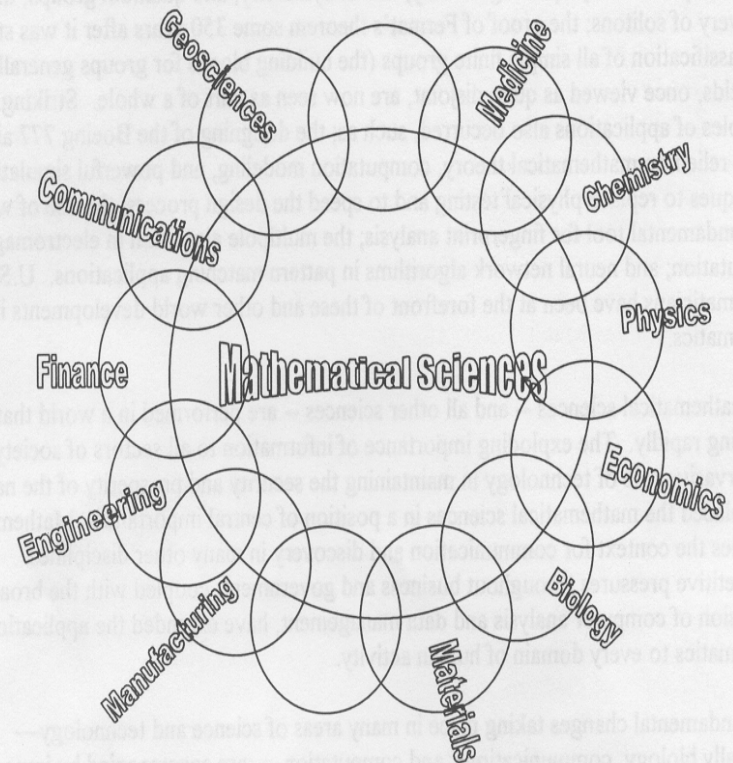
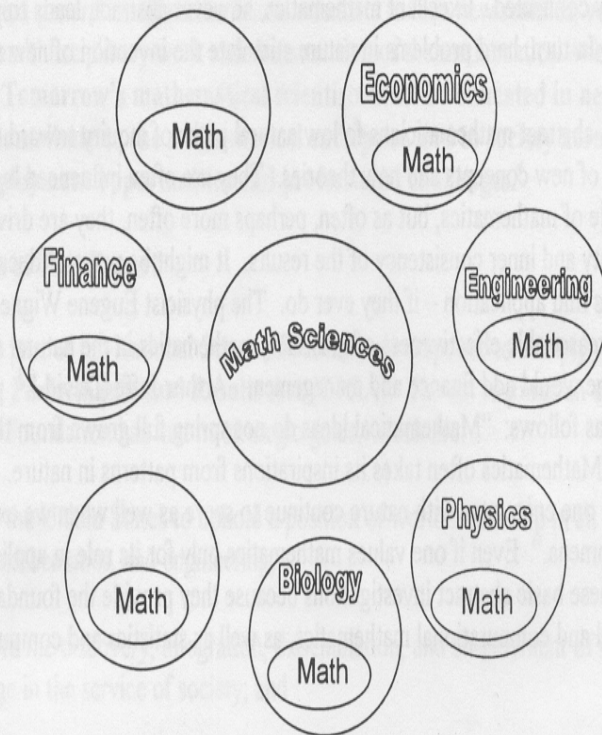
Waikoloa Beach, Hawai'i - November 7, 2007



Outline

- DMS investment philosophy: *discovery, connections, community*
- Examples of mathematics enabling science
- Highlights of DMS awards in EPSCoR states

Which vision is right for Math?



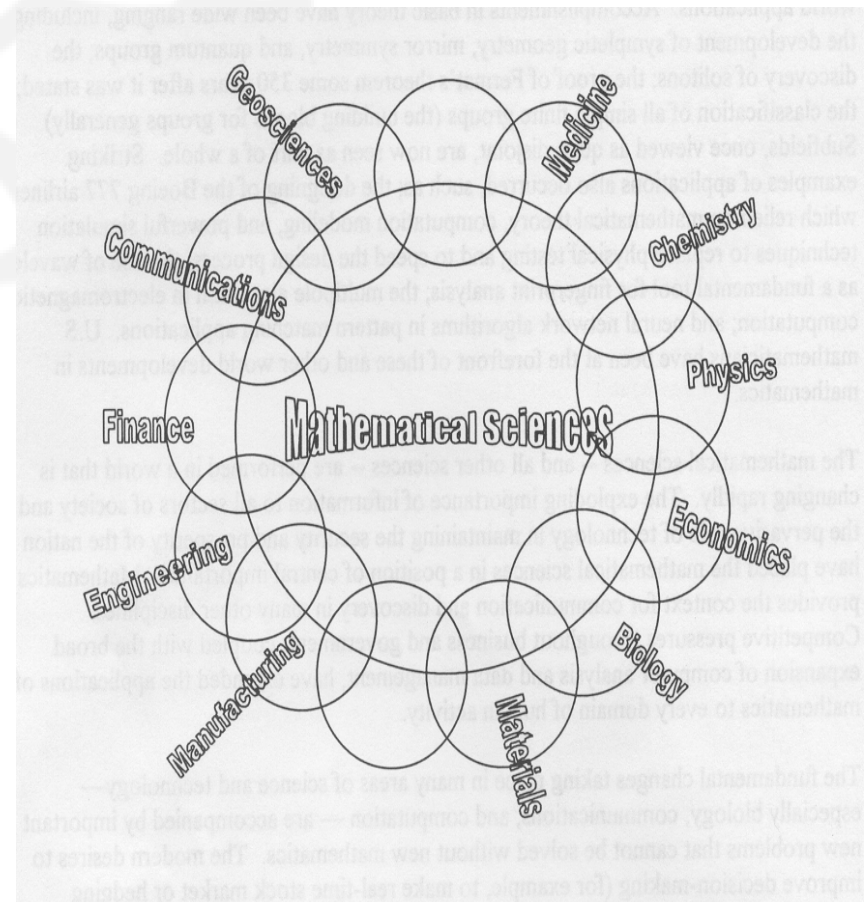
Report of the Senior Assessment Panel..., aka Odom Report, 1998

Connectivity is essential!

*Research in fundamental mathematics and statistics – **discovery***

*Investments in the interactions of mathematical science with other branches of science and engineering – **connections***

*Development of a capable and diverse mathematical sciences workforce for academia, industry, government - **community***



DMS Investment Priorities

➤ Discovery

- *Research grants in core areas of mathematics and statistics*
- *Research grants for interdisciplinary research*

➤ Connections

- *National mathematical sciences research institutes*
- *Conferences and workshops*

➤ Community

- *Training grants for undergraduates, graduates, and postdoctoral researchers*
- *Research Experiences for Teachers*

NSF Investment Priorities

Promote transformational, multidisciplinary research

Investigate the human and social dimensions of knowledge and technology

Further U.S. economic competitiveness

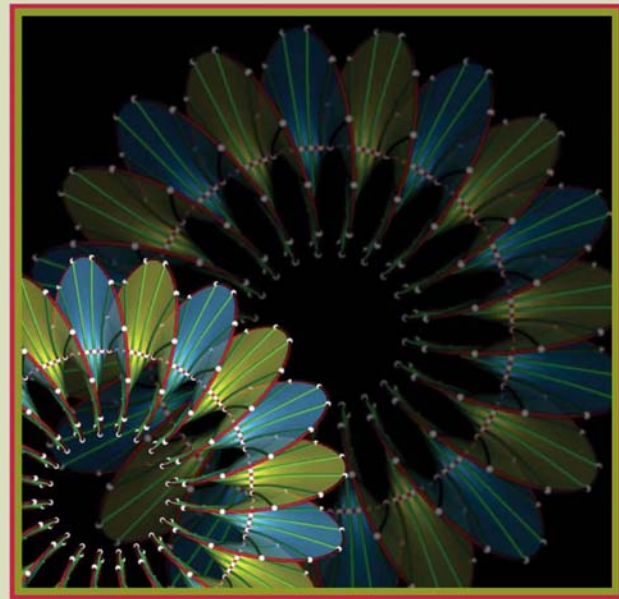
Foster research that improves our ability to live sustainably on Earth

Advance fundamental research in computational science and engineering, and in fundamental, applied and interdisciplinary mathematics and statistics



National Science Foundation

INVESTING IN AMERICA'S FUTURE



STRATEGIC PLAN

FY 2006-2011

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Tracking Products

Number theory, an area of mathematics on which the security of Internet communication is based, also guarantees the authenticity of a book's ISBN (International Standard Book Number) and its UPC (Universal Product Code). Authentic ISBN numbers allow computerized tracking of books, and UPC's identify each book as unique—ensuring that authors get the royalties they're due.

All digits of an ISBN number but the last are multiplied in modular arithmetic by predetermined numbers. The sum of these products is used to create a check digit. The check digit is then appended to the end of the number. Not only does the check digit guard against intentional fraud, but it also detects human error, like transposing two digits. This process is also used with most state driver's licenses and with airline tickets.

More information:

Contemporary Abstract Algebra, Joseph A. Gallian, 1998.



The Mathematical Moments program promotes appreciation and understanding of the role mathematics plays in science, nature, technology, and human culture.

www.ams.org/mathmoments

Number theory is the mathematical foundation for...

Bar Codes

Universal Product Codes

Secure Internet Commerce





Locating, locating, locating

Originally designed for military use, the Global Positioning System (GPS) now lets boaters, drivers, and hikers pinpoint their location to within a few meters. Most of GPS's functionality is derived from arithmetic, algebra, and geometry. The time it takes for a signal to travel from a transmitting satellite to a GPS receiver establishes the distance between the two, which places the GPS user on an imaginary sphere centered at the satellite. Similar calculations are done concurrently using other satellites. Once corrections for the difference between satellite and receiver clocks are made, the GPS user's location must be one of the points of intersection of three spheres.

The basic principles of GPS are simple, but reducing error when using satellites more than 10,000 miles away to calculate locations is not. Information theory extracts reliable data from weak signals (which have less than a billionth of the power of those received by your television) and mathematical models of the atmosphere account for slight changes in speed as signals travel through different layers on their way to earth. Differential GPS reduces error even further by using land-based stationary receivers, whose precise positions are known. Eventually real-time GPS will be so accurate — with errors on the order of inches — that it will guide cars and allow planes to land in zero visibility.

For More Information: "Retooling the Global Positioning System," *Scientific American*, Per Enge, May 2004.

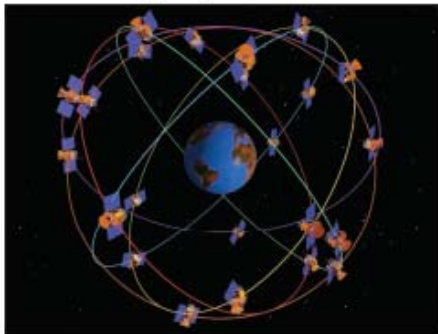


Image courtesy of The Aerospace Corporation.



The *Mathematical Moments* program promotes appreciation and understanding of the role mathematics plays in science, nature, technology, and human culture.

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Geometry and statistics are critical components of the...

Global Positioning System





Predicting Storm Surge

Storm surge is often the most devastating part of a hurricane. Mathematical models used to predict surge must incorporate the effects of winds, atmospheric pressure, tides, waves and river flows, as well as the geometry and topography of the coastal ocean and the adjacent floodplain. Equations from fluid dynamics describe the movement of water, but most often such huge systems of equations need to be solved by numerical analysis in order to better forecast where potential flooding will occur.

Much of the detailed geometry and topography on or near a coast require very fine precision to model, while other regions such as large open expanses of deep water can typically be solved with much coarser resolution. So using one scale throughout either has too much data to be feasible or is not very predictive in the area of greatest concern, the coastal floodplain. Researchers solve this problem by using an *unstructured grid* size that adapts to the relevant regions and allows for coupling of the information from the ocean to the coast and inland. The model was very accurate in tests of historical storms in southern Louisiana and is being used to design better and safer levees in the region and to evaluate the safety of all coastal regions.

For More Information: "A New Generation Hurricane Storm Surge Model for Southern Louisiana", by Joannes Westerink et al.

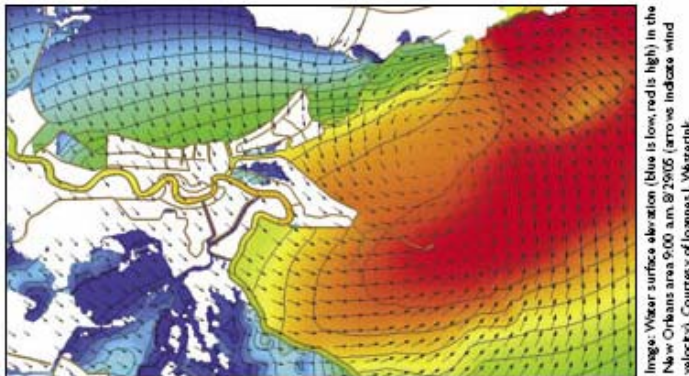


Image: Water surface elevation (blue is low, red is high) in the New Orleans area 9:00 a.m. 8/29/05 (arrows indicate wind velocity). Courtesy of Joannes J. Westerink.



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Computational algorithms and adaptive mesh refinement permit accurate calculation of...

Storm surges and other disruptive weather events





Storing Fingerprints

Storing and identifying the digitized version of millions of fingerprints is an almost inconceivably enormous task. Uncompressed, the FBI's current fingerprint files would consist of 200 terabytes (200,000,000,000,000 bytes). A new piece of mathematics, wavelets, makes data compression fast, relatively routine, and much less expensive so that storage is feasible and retrieval is fast.

Any image is really a function that gives the color and intensity of each pixel. This function can be written as a combination of special functions—the wavelets. The rules for how the wavelets fit together are easier to store and retrieve than the function itself. Wavelets are a twofold improvement over Fourier transforms—another data compression technique based on sines and cosines.

For More Information:

What's Happening in the Mathematical Sciences, Vol. 2, Barry Cipra.



Photograph courtesy of Christopher M. Brislawn, Los Alamos National Lab.



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Wavelets and harmonic analysis are the key ideas behind...

Data compression for efficient storage and retrieval of fingerprints





Seeing More Clearly

Twinkling stars are fun for songs but frustrating for astronomers. Current technology uses *adaptive optics* to adjust for turbulence in the atmosphere and deliver an accurate image of stars, planets, and satellites. Correcting for atmospheric distortion involves linear algebra, geometry, and statistics to determine the extent of the distortion and continually adjust deformable mirrors which refocus light waves back along their true paths.

Mathematical algorithms make possible the many real-time calculations required to clarify views both beyond earth and under the microscope. In fact, adaptive optics allowed researchers their first views of individual cells in a living eye. This has brought about the potential for better diagnostics and more accurate surgery, so that a science created to help some people see a few things more clearly may help millions see everything better.

For More Information: *Adaptive Optics in Astronomy*, François Roddier.



Image courtesy of the European Southern Observatory.



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Statistics and numerical linear algebra are key components of...

Adaptive optics



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Lisa J. Fauci
Professor of Mathematics
Tulane University

NSF Highlights

Integrative Models of Microorganism Motility

Highlight ID: 14346

Recent biological studies have shed light on the relative importance of the mechanical ingredients of reproduction. Mammalian fertilization requires coordinated activity of motile spermatozoa, muscular contractions of the uterus and oviduct, and ciliary beating. The understanding of the internal mechanics of cilia and flagella, flagellar surface interaction, sperm motility in complex fluids and the role of fluid dynamics in embryo transfer has also seen recent advances. Despite considerable progress in modeling these elements individually, relatively few studies have examined the fluid dynamic coupling of these elements. Fauci, et al, have developed promising computational fluid dynamics techniques that can be used to investigate these complicated fluid-structure interactions. This study shows that the observed swimming behavior of a motile organism is the result of a complex interplay of internal force generation, passive elastic properties of the structure, and a surrounding viscous fluid. A unified computational approach, based upon an immersed boundary framework, has been developed, coupling internal force-generating mechanisms of organisms with an external, viscous, incompressible fluid. These advances in computational biological fluid dynamics promise to provide a framework for robust and accurate simulations of these complex, coupled dynamical systems.

Primary Strategic Outcome Goal:

- Discovery: Foster research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.

Secondary Strategic Outcome Goals:

- Learning: Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens.

How does this highlight address the strategic outcome goal(s) as described in the [NSF Strategic Plan 2006-2011](#)?

This project draws ideas from many disciplines, including fluid mechanics, scientific computing, cell biology, and numerical analysis. This multidisciplinary approach has enabled the researchers to make significant progress in the understanding of microorganism motility. In addition, this interdisciplinary project has formed the basis for involvement and training of students at all levels, from undergraduate to graduate to postdoctoral researchers.

Does this highlight represent transformative research?

No

MPS/DMS 2007

Program Officer: Mary Ann Horn

NSF Award Numbers:

[0201053](#)

Award Title: Integrative Models of Microorganism

Motility

PI Name: Lisa Fauci

Institution Name: Tulane University

PE Code: 7334

NSF Contract Numbers:

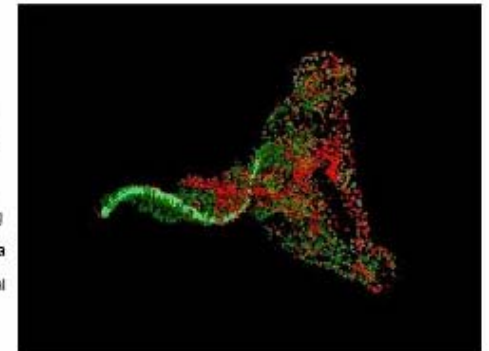
NSF Investments: American Competitiveness Initiative (ACI)

Related Center or Large Facility:

Submitted on 02/26/2007 by Mary Ann Horn

DMS: Approved 02/26/2007 by Deborah Lockhart

MPS: Approved 02/28/2007 by Lorretta J. Hopkins



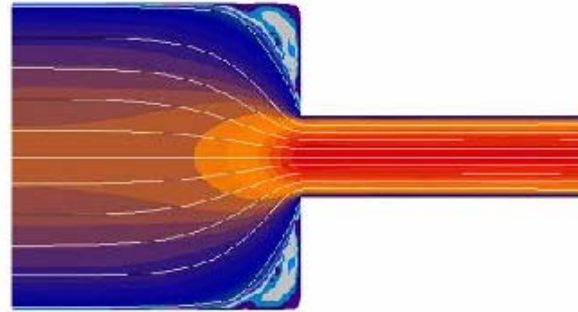
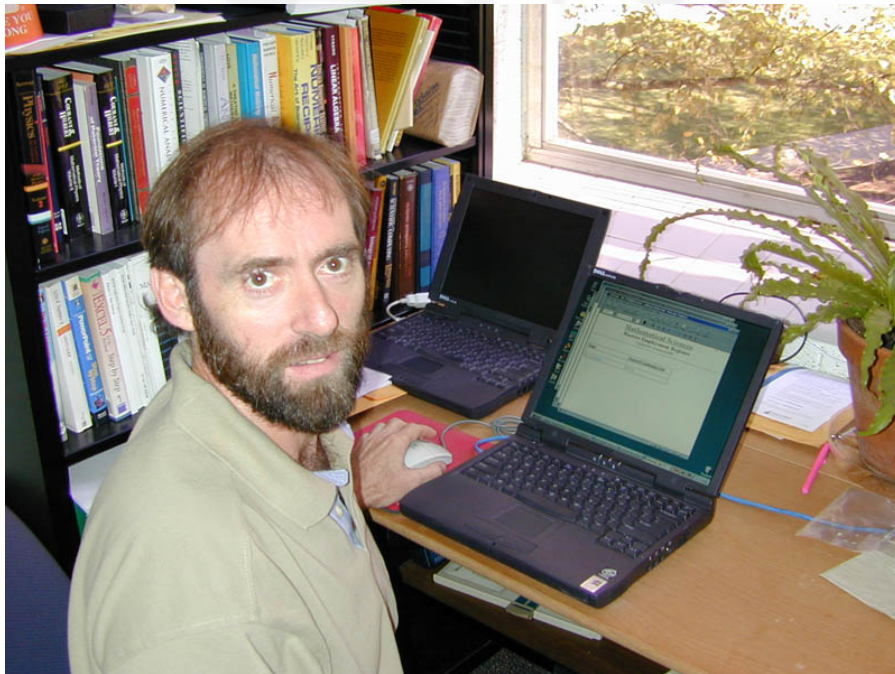
Computational simulation: Swimming leech with particles—side view. Initial position consists of leech encased in cylinder made out of red, green, and gold particles. As leech swims, the forces created disperse the particles through the fluid.

Permission Not Granted

NSF Highlights

The Numerical Simulation of Viscoelastic Fluid Flow

Highlight ID: 12387



Vincent Ervin
Professor of Mathematics
Clemson University

Numerical simulation of a viscoelastic fluid through a 4:1 planar contraction.

Permission Granted

Credit: Vincent Ervin

Viscoelastic fluids, in which the internal stress of the fluid cannot be simply described by the rate of deformation, are abundant in nature (blood) and manufacturing processes (molten polymers). Active research in the numerical simulation of these fluids leaves many open and challenging problems in both theoretical and computational domains. This research has addressed shortcomings in the present state of the science and has expanded the mathematical foundations of solution methods.

One application of the research on computational analysis of viscoelastic fluid flow is the development of accurate and stable approximation methods for mathematical models of fluid flow. A better understanding of such computations can lead to a better understanding of blood flow and better medical tools that address blood flow ailments.

Primary Goal Indicators:

- Cyberinfrastructure

Secondary Goal Indicators:

- Contributions

This work is notable because:

This nugget represents modern computational methods at the forefront of methods that can enhance techniques for cyberinfrastructure.

Other indicators (Is this work transformative or multidisciplinary?):

This work involves multidisciplinary research.



Tom Marley
Professor of Mathematics
University of Nebraska, Lincoln
(and a future mathematician?)

NSF Highlights

Nebraska Mentoring through Critical Transition Points (MCTP)

Highlight ID: 14024

Two critical transition periods in the preparation of mathematicians are being targeted: the transition from the undergraduate to the graduate level, and the transition from the advanced graduate level to the early years of an academic position. The 2006 Nebraska IMMERSE programs helped prepare another 17 pre-graduate students for their first year in graduate school, gave 10 more graduate students extensive experience in mentoring, and provided 4 more early-career faculty a valuable opportunity for professional development, including enhancing their research programs.

The 2006 KRA (Keeping Research Alive) workshop provided an opportunity for 3 more recent Ph.D.s to come to Lincoln for 2-3 weeks and reinvigorate their research by meeting with University of Nebraska-Lincoln faculty and research visitors as well as the other early career faculty.

The 2006 Nebraska Conference for Undergraduate Women in Mathematics gave 188 undergraduate women an opportunity to present their research and/or meet other women in mathematics, including the distinguished panelists and plenary speakers.

The three new first-year and 4 new advanced MCTP trainees received release from teaching in order to focus on their classes, examinations, and research, as well as attend the special MCTP seminars (Landscape Seminar, Teaching Seminar, and the Professional Development Seminar).

All three first year trainees passed the qualifying exams on their first try in June 2006.

Primary Strategic Outcome Goal:

- Discovery: Foster research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.

Secondary Strategic Outcome Goals:

How does this highlight address the strategic outcome goal(s) as described in the [NSF Strategic Plan 2006-2011](#)?

This program targets two critical transition periods in the preparation of mathematicians: the transition from the undergraduate to the graduate level, and the transition from the advanced graduate level to the early years of an academic position. At both of these transition periods, the program focuses on interactions between non-PhD granting colleges and universities (referred to as "four-year colleges" for simplicity) and Ph.D.-granting research universities. The program will benefit students at UNL as well as developing mathematicians in the larger mathematical community.

Does this highlight represent transformative research?

No

MPS/DMS 2007

Program Officer: Lloyd Douglas

NSF Award Numbers:

[0354281](#)

Award Title: EMSW21-MCTP: Nebraska Mentoring through Critical Transition Points

PI Name: Judy Walker

Institution Name: University of Nebraska-Lincoln

PE Code: 1260

NSF Contract Numbers:

NSF Investments: American Competitiveness Initiative (ACI), Educating Innovators for the 21st Century

Related Center or Large Facility:

Submitted on 02/26/2007 by Lloyd E. Douglas

DMS: Approved 02/26/2007 by Deborah Lockhart

MPS: Approved 02/26/2007 by Loretta J. Hopkins



IMMERSE

Permission Not Granted

DMS staff from EPSCoR states



Mary Ann Horn
Vanderbilt University, Tennessee – Mathematical Biology



Tomek Bartoszynski
Boise State University, Idaho – Logic and Foundations



Joanna Kania-Bartoszyńska
Boise State University, Idaho – Topology

Conclusions

- Mathematical sciences research is lively, vital, and developing rapidly
- Research in mathematics and statistics enables progress in science and technology
- Mathematical sciences play a critical role in developing a science and technology workforce