

Workshop to Build an EPSCoR  
Consortium to *Lead the Nation*  
on Innovating Nanoscale  
Ferroelectric & Multiferroic  
Science, Technology, and  
Workforce Development

# Why Nanoscale Ferroelectric & Multiferroic Science, Technology, & Workforce?

*Driven by two science and technology opportunities:*

- 1. An exciting opportunity based on our ability to create new and novel materials that exhibit behavior that is superior to any we know. Imagine smaller, stronger, lighter, faster materials that are creatively used to innovate the next generation of high technology.**
- 2. This opportunity is based on cyber infrastructure to develop nanoscale ferroelectric & ferromagnetic superlattices and arrays that are computationally designed in advance to have a desired behavior before they are fabricated, and then tested with the predicted behavior, and fabricated into devices.**

*Imagine the power of this combination!*

# Chemical Periodic Table

## Superior Behavior

<p><b>Atomic Weight</b> ( ) indicates longest-lived isotope</p> <p><b>Acidity/Basicity<sup>2</sup> &amp; Crystal Structure<sup>3</sup></b></p> <p><b>Melting Point<sup>5</sup>, °C</b></p> <p><b>Boiling Point<sup>5</sup>, °C</b></p> <p><b>Density<sup>6</sup> (300 K), g/cm<sup>3</sup></b> for gases: g/L, 273.15 K, 1 atm</p> <p><b>Electronegativity</b></p>																																																																									
<p><b>Group Classifications<sup>4</sup></b></p> <p><b>Atomic Number</b></p> <p><b>Oxidation States</b> bold indicates most stable state</p> <p><b>Symbol<sup>1</sup></b></p> <p><b>Electronic Configuration</b></p> <p><b>Name</b></p>																																																																									
<p><b>1 IA</b></p> <p><b>2 IIA</b></p> <p><b>3 IIIB</b></p> <p><b>4 IVA</b></p> <p><b>5 VA</b></p> <p><b>6 VIA</b></p> <p><b>7 VIIA</b></p> <p><b>8 VIIIA</b></p> <p><b>9 VIIIA</b></p> <p><b>10 VIIIA</b></p> <p><b>11 IB</b></p> <p><b>12 IIB</b></p> <p><b>13 IIIB</b></p> <p><b>14 IVB</b></p> <p><b>15 VB</b></p> <p><b>16 VIB</b></p> <p><b>17 VIIB</b></p> <p><b>18 VIII</b></p>																																																																									
1 1 1.00794 H Hydrogen	2 4 4.002602 He Helium	3 7 6.941 Li Lithium	4 9 9.012182 Be Beryllium	5 11 22.989768 Na Sodium	6 12 24.30509 Mg Magnesium	7 21 44.955910 Sc Scandium	8 22 47.88 Ti Titanium	9 23 50.9415 V Vanadium	10 24 51.9961 Cr Chromium	11 25 54.93805 Mn Manganese	12 26 55.847 Fe Iron	13 27 58.93320 Co Cobalt	14 28 58.93320 Ni Nickel	15 29 63.546 Cu Copper	16 30 65.38 Zn Zinc	17 31 69.723 Ga Gallium	18 32 72.61 Ge Germanium	19 33 74.92159 As Arsenic	20 34 78.96 Se Selenium	21 35 79.904 Br Bromine	22 36 83.80 Kr Krypton	23 37 85.4678 Rb Rubidium	24 38 87.62 Sr Strontium	25 39 88.90585 Y Yttrium	26 40 89.9063 Zr Zirconium	27 41 90.948 Nb Niobium	28 42 92.90638 Mo Molybdenum	29 43 95.94 Tc Technetium	30 44 97.9072 Ru Ruthenium	31 45 101.07 Rh Rhodium	32 46 102.90550 Pd Palladium	33 47 106.42 Ag Silver	34 48 107.8682 Cd Cadmium	35 49 112.411 In Indium	36 50 114.818 Sn Tin	37 51 118.710 Sb Antimony	38 52 121.757 Te Tellurium	39 53 127.60 I Iodine	40 54 126.90447 Xe Xenon	41 55 132.90545 Cs Cesium	42 56 137.327 Ba Barium	43 57 138.9055 La Lanthanum	44 58 139.9053 Ce Cerium	45 59 140.90768 Pr Praseodymium	46 60 144.24 Nd Neodymium	47 61 144.9127 Pm Promethium	48 62 150.36 Sm Samarium	49 63 151.965 Eu Europium	50 64 157.25 Gd Gadolinium	51 65 158.92534 Tb Terbium	52 66 162.50 Dy Dysprosium	53 67 164.93032 Ho Holmium	54 68 167.25 Er Erbium	55 69 168.93421 Tm Thulium	56 70 173.04 Yb Ytterbium	57 71 174.967 Lu Lutetium	58 88 223.0197 Fr Francium	59 89 226.0254 Ra Radium	60 90 227.0277 Ac Actinium	61 91 227.0337 Th Thorium	62 92 231.03688 Pa Protactinium	63 93 238.02891 U Uranium	64 94 238.02891 Np Neptunium	65 95 238.02891 Pu Plutonium	66 96 244.06422 Am Americium	67 97 244.06422 Cm Curium	68 98 247.07033 Bk Berkelium	69 99 247.07033 Cf Californium	70 100 251.07966 Es Einsteinium	71 101 252.083 Fm Fermium	72 102 257.0951 Md Mendelevium	73 103 258.10 No Nobelium	74 104 259.10888 Lr Lawrencium

**PERMA-CHART**  
Science Series  
PAPERTECH

58 82 137.327 Ce Cerium	59 82 140.90768 Pr Praseodymium	60 82 144.24 Nd Neodymium	61 82 144.9127 Pm Promethium	62 82 150.36 Sm Samarium	63 82 151.965 Eu Europium	64 82 157.25 Gd Gadolinium	65 82 158.92534 Tb Terbium	66 82 162.50 Dy Dysprosium	67 82 164.93032 Ho Holmium	68 82 167.25 Er Erbium	69 82 168.93421 Tm Thulium	70 82 173.04 Yb Ytterbium	71 82 174.967 Lu Lutetium	90 88 226.0254 Th Thorium	91 88 231.03688 Pa Protactinium	92 88 238.02891 U Uranium	93 88 238.02891 Np Neptunium	94 88 238.02891 Pu Plutonium	95 88 244.06422 Am Americium	96 88 244.06422 Cm Curium	97 88 247.07033 Bk Berkelium	98 88 247.07033 Cf Californium	99 88 251.07966 Es Einsteinium	100 88 252.083 Fm Fermium	101 88 257.0951 Md Mendelevium	102 88 258.10 No Nobelium	103 88 259.10888 Lr Lawrencium
-------------------------------------	---	---------------------------------------	--	--------------------------------------	---------------------------------------	--	--	--	--	------------------------------------	--	---------------------------------------	---------------------------------------	---------------------------------------	---	---------------------------------------	--	--	--	---------------------------------------	--	--	--	---------------------------------------	--	---------------------------------------	--

# What is Special About Nanoscale Ferroelectrics and Multiferroics?

*Electric Field  
Switches*

**Semiconductor**

*Semiconductor  
Behavior*

**Ferroelectric**

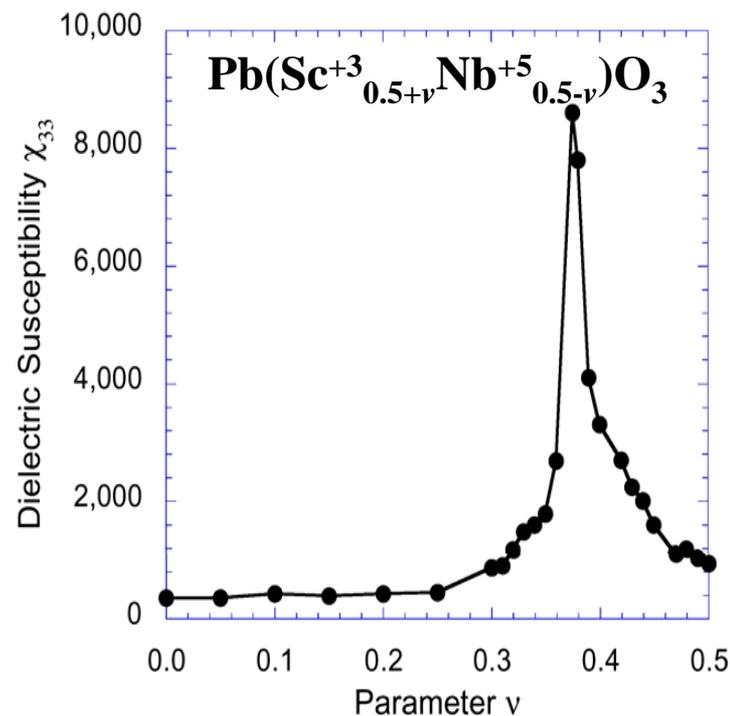
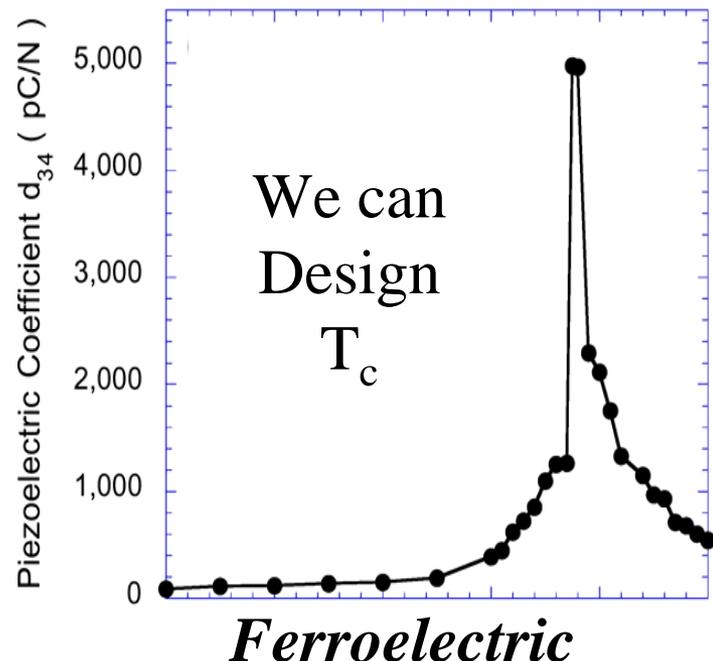
*Electric Field  
changes Magnetic  
Behavior*

**Magnetic**

**Ferroelectric**

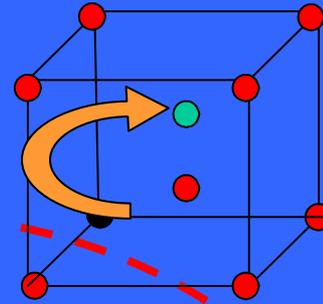
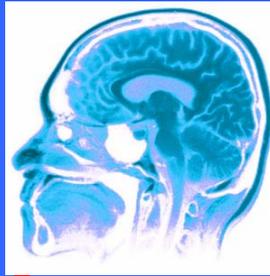
**Magnetic    Ferroelectric**

*Switching between Magnetic  
and Electric Behavior*



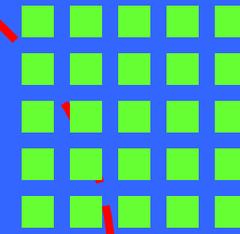
# Potential Payoff is Difficult to Overestimate

*Sensitive  
IR/Magnetic Field  
Sensors*

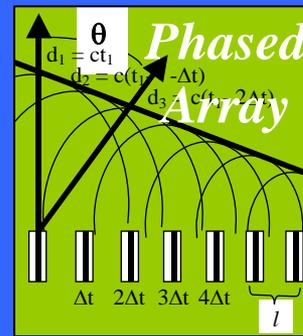
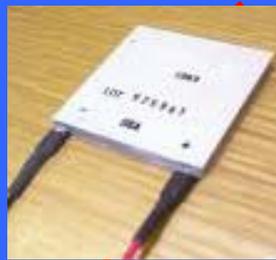


*Faster-Lower Power  
Memory Cell*

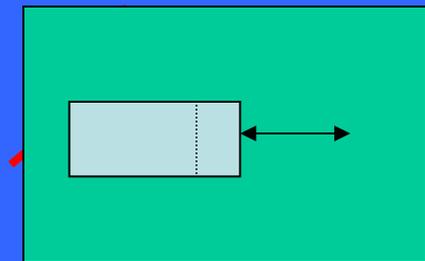
*New Era of  
Electronics  
based on a  
new  
paradigm*



*Thermoelectric  
to convert  
waste heat to  
electricity*

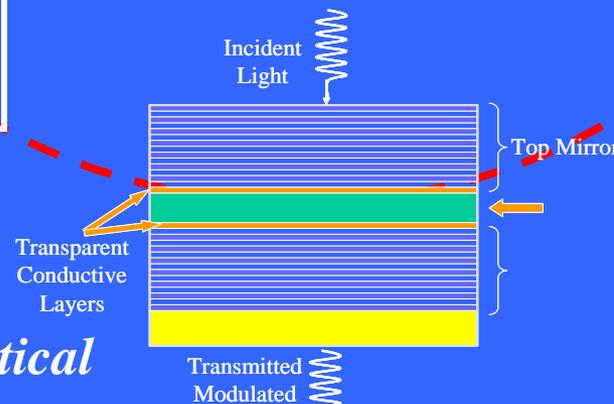


*Invisible  
Material*



*Fast-Giant  
Displacement Piezo  
Actuators*

*Ultra-fast Optical  
Switch*



# Consortium

Despite this potential, there is currently no such innovative material/device effort in the U.S. *However, this talent does uniquely exist today among several of the EPSCoR states.* A consortium will bring together this unique interdisciplinary mix of people, ideas, and tools to have a larger impact, breaking down the barriers that prevent realization of this vast potential.



This is something that no single institution can do effectively on its own.

# But A Consortium of EPSCoR States can

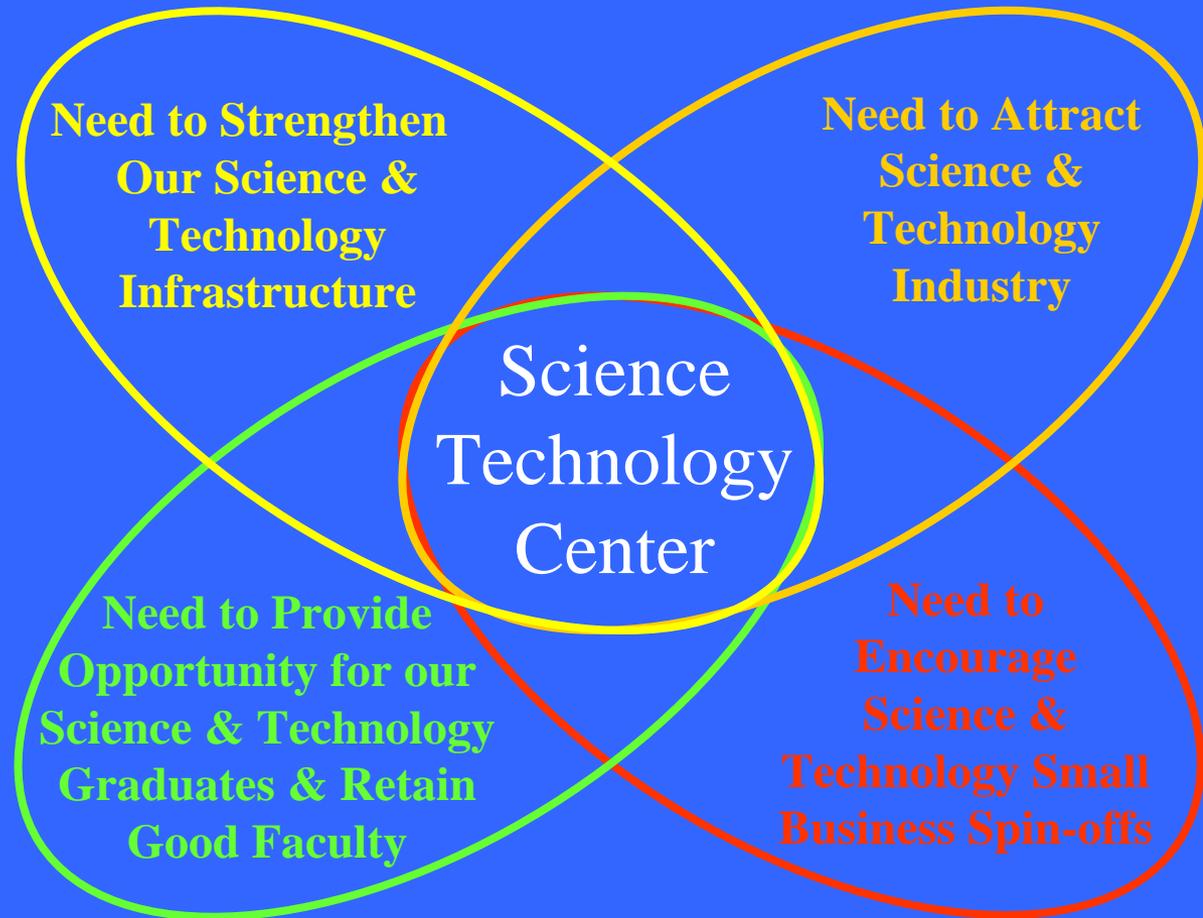
*Bring The Needed  
Pieces Together*

*To Compete for a  
Science and Technology  
Center on Nanoscale  
Ferroelectrics and  
Multiferroics that can  
have this Technology  
Impact*



Moreover, the Proposed STC Consortium can have a Big Impact on many of the Needs EPSCoR States have in Common.

*Innovation through an STC is Key*



# How do we Achieve a Competitive Consortium?

*One approach is where one person selects partners and then writes the proposal for an NSF Center with partners just looking on*



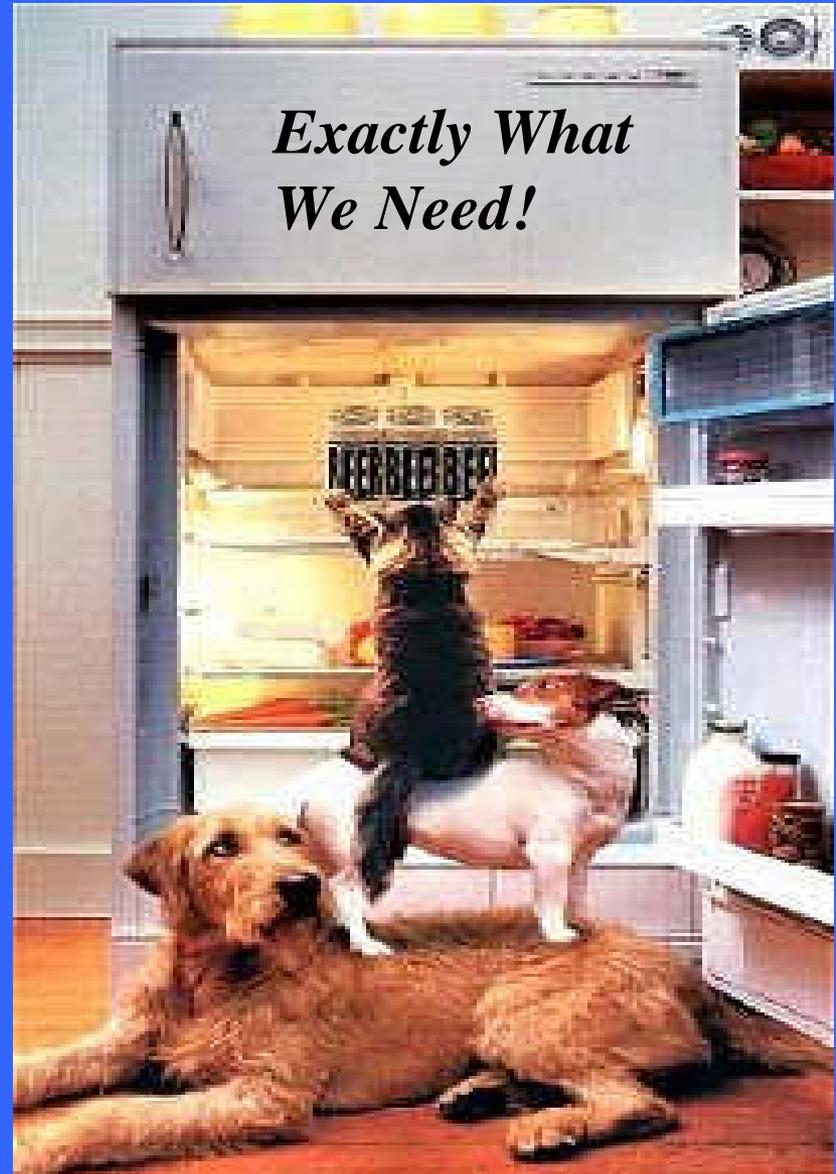
***What We  
Need To  
Avoid!***

*A Second approach takes the word “team” to mean that one person tells everyone what to do to write a competitive proposal for an NSF Center*



*Exactly What  
We Need!*

*But a Workshop has  
the best chance to  
help us achieve the  
right mix of people,  
ideas, and tools to  
form a competitive  
NSF Center  
proposal*



The Workshop Is Built Around a solicitation that resulted in 45 participants from 12 EPSCoR States and Structured into 7 Parts:

- ❖ Growth
- ❖ Theory/Modeling
- ❖ Characterization and Imaging
- ❖ Device Fabrication and Demonstration
- ❖ Human Resource Development
- ❖ Innovation and Technology Transfer
- ❖ STC Proposal Building

While Each Person Presents a 10 minute Discussion  
Each Participant Answers the Following for each of the  
7 Parts as it Applies to a Competitive STC Proposal

**“GROWTH” PART**

**YOUR NAME:**

**YOUR DISCIPLINE / EXPERTISE:**

**Strengths:**

**Uniqueness:**

**Need for Addition:**

**Potential for Scientific, Technological, or Educational Breakthroughs:**

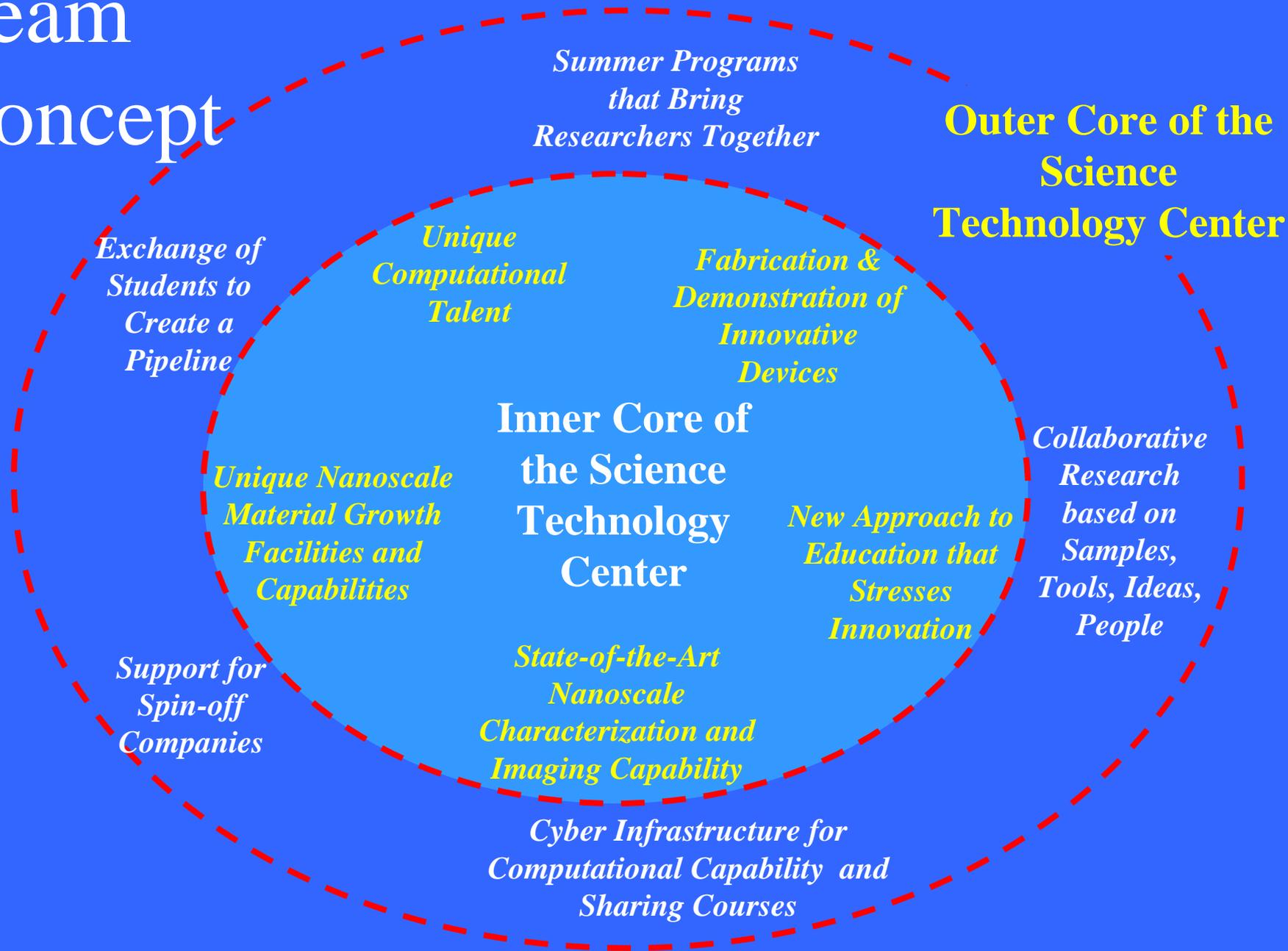
**Expected Challenges:**

**Possible National Impacted:**

**Suggest Focus:**

**Suggested Strategic Goals:**

# Team Concept



NEED CASH  
For STC  
RESEARCH



# I Need Your Help

“Institutional Commitment (one-page limit). Provide a synopsis of institutional and other support of the proposed Center. Outline the lead institution's commitment: space (new space and/or renovations to existing facilities), faculty and staff positions, capital equipment, and access to facilities and instrumentation. Major commitments of partner institutions should also be described. Describe how the commitment contributes to realizing the strategic goals of the integrated Center. Describe support from all other sources that has been committed, including space, facilities, and personnel for the Center. Note that cost sharing is not required; voluntary cost sharing, if provided, will not influence the review process.”